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Experimental Study of the Effectiveness of Weld Buttering for the Repair of Corroded Pressure Hulls

Final Report

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Martec Limited

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Contractor's Document Number: C-FER Report F034
Contract Project Manager: Chris Timms, 780-450-8989 ext 259
PWGSC Contract Number: W7707-098210/001
Contract Scientific Authority: John R. MacKay, 902-426-3100 ext 382

Defence R&D Canada – Atlantic

Contract Report
DRDC Atlantic CR 2011-334
February 2012

Canada

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February 2012

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Abstract

C-FER Technologies (1999) Inc. (C-FER) was awarded Contract Number W7707-098210/001/HAL with Public Works and Government Services Canada (PWGSC) to design, fabricate and test large-scale ring-stiffened cylinders. The objective of this project was to assess the impact on the collapse pressure of submarine pressure hulls of metal loss due to corrosion, with and without subsequent weld buttering repair. C-FER and Martec Limited ("Martec") contributed to the preparation of this report and the work. Martec was responsible for the final cylinder design and finite element (FE) analysis, while C-FER was responsible for providing technical support on the end cap design, collapse testing facilities, testing expertise and overall project coordination. The three specimens, designated as Specimen A – Baseline, Specimen B – Damaged and Specimen C – Repaired, were fabricated and tested, and the resulting collapse pressures were 7.75, 7.31 and 7.66 MPa, respectively. The simulated corrosion damage (i.e. metal loss) reduced the collapse capacity by 5.9%, whereas repair of simulated corrosion damage by metal replacement through weld buttering recovered 4.8% of that capacity. The findings indicate that weld buttering can be an effective corrosion repair technique.

Résumé

C-FER Technologies (1999) Inc. s'est vue attribuer le contrat W7707-098210/001/HAL par Travaux publics et Services gouvernementaux Canada (TPSGC) pour la conception, la fabrication et l'essai de cylindres à grande échelle renforcés à l'aide d'anneaux. L'objectif de ce projet était d'évaluer l'impact, sur la pression d'effondrement de coques épaisses de sous-marins, de la perte de métal par corrosion, avec et sans beurrage subséquent. C-FER et Martec Limited ont contribué à la préparation du présent rapport et aux travaux. Martec était responsable de la conception finale des cylindres et de l'analyse par éléments finis, alors que C-FER était chargée de fournir du soutien technique portant sur la conception du bouchon d'extrémité, ainsi que les installations d'essai d'effondrement, l'expertise d'essai, et de faire la coordination du projet. Les trois spécimens, désignés de la façon suivante : spécimen A – point de comparaison, spécimen B – endommagé, et spécimen C – réparé, ont été fabriqués et testés, et les pressions d'effondrement résultantes étaient de 7,75, 7,31 et 7,66 MPa respectivement. Les dommages par corrosion simulés (c.-à-d. les pertes de métal) ont réduit la capacité d'effondrement de 5,9 %, alors que la réparation des dommages par corrosion simulés par remplacement de métal par beurrage a permis de récupérer 4,8 % de cette capacité. Les conclusions indiquent que le beurrage peut être une technique de réparation de la corrosion efficace.

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Executive summary

Experimental Study of the Effectiveness of Weld Buttering for the Repair of Corroded Pressure Hulls: Final Report

Doug Swanek; Chris Timms; Rick Link; DRDC Atlantic CR 2011-334; Defence R&D Canada – Atlantic; February 2012.

Introduction: Wastage of a submarine pressure hull by corrosion can significantly reduce its collapse strength, to an extent that may require the submarine's diving depth to be restricted. The thickness of corroded hull plating is often restored by weld buttering, whereby weld material is applied to the affected area and ground flush with the surrounding intact plating. Weld buttering (also known as weld overlay, build-up or cladding) is a convenient and cost effective choice, especially compared to more drastic repair options like the complete replacement of the corroded hull plating. Nonetheless, there are concerns with weld repairs, especially the impact of weld distortions and residual stresses on hull collapse. The work described in this report was designed to study the effectiveness of weld buttering through pressure hull collapse tests.

Results: Three ring-stiffened cylinders were fabricated from HY80 steel using conventional methods for submarine construction, i.e. cold rolling and welding. The test specimens were approximately one-sixth scale, with reference to conventional diesel-electric submarines hulls. Artificial corrosion was applied to two of the specimens by milling away approximately 20% of the plating thickness in a square patch covering one frame bay. The corrosion damage on one of those specimens was repaired by weld buttering. The collapse pressure of the cylinder with unrepaired corrosion damage was found to be 5.7% less than a similar intact cylinder with no damage. The loss of strength was mainly due to early yielding at the plate thinning. Premature yielding was less pronounced in the weld buttered cylinder, which was only 1.2% weaker than the intact specimen. It is possible that the small difference in the strengths of the intact and repaired cylinders is due to the large distortions and stresses that arose due to buttering. On the other hand, the discrepancy may be explained by random scatter that affects all test results.

Significance: The experiments showed that weld buttering can reclaim 80% of the collapse strength that is lost due to corrosion damage. In most cases, that margin would be sufficient to negate the need for corrosion related diving restrictions for in-service submarines. The experiments also alleviate concerns related to distortions and stresses that are introduced during weld buttering, since those secondary effects were not found to significantly affect collapse strength despite being of large magnitude. Furthermore, it is expected that the relative magnitude of weld distortions and stresses would be smaller in real hulls due to scaling effects with the test cylinders. Therefore, weld buttering may be able to reclaim an even greater percentage of the collapse pressure for a full-scale hull.

Future plans: The test results will be used to validate the SubSAS submarine structural modelling software, as well as other computer programs that are used to simulate hull collapse and weld procedures. In fact, some of that modelling work is presented in the current report. The validated modelling methodology will then be used to study a greater range of corrosion and weld buttering cases than was practical in the experimental program. Those analyses will be used to make recommendations regarding the limitations of weld buttering.

Sommaire

Experimental Study of the Effectiveness of Weld Buttering for the Repair of Corroded Pressure Hulls: Final Report

Doug Swanek; Chris Timms; Rick Link; DRDC Atlantic CR 2011-334; R & D pour la défense Canada – Atlantique; février 2012.

Introduction ou contexte: La détérioration d’une coque épaisse de sous-marin par corrosion peut diminuer de façon importante sa résistance à l’effondrement au point que l’on pourrait devoir restreindre la profondeur de plongée du sous-marin. L’épaisseur du bordé de carène corrodé est souvent restaurée par beurrage, méthode où du matériau de soudage est appliqué à la surface touchée et meulé jusqu’au niveau du bordé de carène intact environnant. Le beurrage (aussi connu sous le nom de recouvrement de soudure, accumulation ou surfaçage) est un choix pratique et rentable, en particulier en comparaison à des options de réparation plus radicales comme le remplacement complet du bordé de carène corrodé. Néanmoins, il pourrait y avoir certains problèmes avec les réparations par soudure, en particulier les conséquences des distorsions et des contraintes résiduelles sur l’effondrement de la coque. Les travaux décrits dans le présent rapport ont été conçus pour étudier l’efficacité du beurrage par le biais d’essais d’effondrement de coque épaisse.

Résultats: Trois cylindres renforcés à l’aide d’anneaux ont été fabriqués à partir d’acier HY80 grâce à des méthodes classiques pour la construction de sous-marins, c.-à-d. le soudage et le laminage à froid. L’échelle des spécimens d’essai était d’environ un sixième, avec référence aux coques de sous-marin diesel-électrique classique. De la corrosion artificielle a été appliquée sur deux des spécimens en enlevant par fraisage environ 20 % de l’épaisseur du bordé de carène dans un morceau rapiécé de forme carrée couvrant l’espace entre deux couples. Les dommages par corrosion sur l’un de ces spécimens ont été réparés par beurrage. La pression d’effondrement du cylindre comportant des dommages de corrosion non réparés s’est avérée être 5,7 % plus petite que celle d’un cylindre intact semblable non endommagé. La perte de résistance était principalement due au fléchissement précoce à l’amincissement du bordé de carène. Le fléchissement prématuré était moins prononcé dans le cylindre beurré, qui était seulement 1,2 % plus faible que le spécimen intact. Il est possible que la petite différence entre la résistance du cylindre intact et celle du cylindre réparé soit due aux grandes distorsions et contraintes qui ont découlé du beurrage. D’autre part, la différence peut être expliquée par la dispersion aléatoire qui influe sur tous les résultats d’essai.

Portée: Les expériences ont montré que le beurrage peut permettre de regagner 80 % de la résistance à l’effondrement perdue à cause des dommages par corrosion. Dans la plupart des cas, cette marge serait suffisante pour qu’il ne soit pas nécessaire d’imposer, aux sous-marins en service, des restrictions à la plongée liées à la corrosion. Les expériences, aussi, diminuent les inquiétudes liées aux distorsions et aux contraintes qui sont introduites pendant le beurrage, car ces effets secondaires ne semblent pas avoir une incidence importante sur la résistance à l’effondrement, même s’ils sont importants. De plus, on s’attend à ce que la magnitude relative des contraintes et des distorsions soit plus petite dans le cas de coques réelles à cause des effets d’écaillage avec les cylindres d’essai. Donc, le beurrage pourrait permettre de regagner un pourcentage encore plus grand de la pression d’effondrement d’une coque grandeur nature.

Recherches futures: Les résultats d'essai seront utilisés pour valider le logiciel de modélisation de structure de sous-marin SubSAS, ainsi que d'autres logiciels utilisés pour simuler l'effondrement d'une coque et les procédures de soudage. En fait, une partie de ces travaux de modélisation est présentée dans le présent rapport. La méthodologie de modélisation validée sera ensuite utilisée pour étudier une plage plus importante de cas de beurrage et de corrosion qu'il n'a été possible de le faire dans le programme expérimental. Ces analyses seront utilisées pour faire des recommandations sur les limites du beurrage.

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1 Introduction

1.1 Terms of Reference

C-FER Technologies (1999) Inc. (C-FER) was awarded Contract Number W7707-098210/001/HAL with Public Works and Government Services Canada (PWGSC) to design, fabricate and test three large-scale ring-stiffened steel cylinders. The objective of this project was to assess the impact on the collapse pressure of submarine pressure hulls of metal loss due to corrosion, with and without subsequent weld buttering repair.

1.2 Project Scope of Work

The project involved the design, fabrication and collapse testing of three initially identical large-scale ring-stiffened cylinders. The work scope included the following: testing of a “baseline” specimen as initially fabricated; the testing of a “damaged” specimen that contained an area of reduced shell wall thickness that was intended to simulate corrosion; and the testing of a “repaired” specimen that also contained an area of reduced wall thickness that was subject to metal replacement by weld buttering (also referred to as weld overlay, build-up or cladding). This report addresses the following aspects of the project:

- Final cylinder design:
  - Predicted collapse pressure; and
  - Design methodology and fabrication drawings.
- Cylinder fabrication:
  - Shell, T-frame and end cap fabrication; and
  - Weld procedures.
- Geometric surveys:
  - Out-of-circularity (OOC) measurements; and
  - Wall thickness measurements.
- Predictive FE analysis:
  - Modelling cylinder Specimen A – Baseline; and
  - Predicting the collapse pressure and failure mode.
- Coupon Testing:
  - Results for material properties; and
  - Stress-strain curves.
- Collapse Testing:
  - Results for each cylinder model; and
  - Pressure-strain curves.

2 Specimen Design

2.1 Overview

The initial design of the ring-stiffened cylinder specimens was based on the following criteria and constraints:

1. The interframe buckling load should be between 4.2 and 4.5 MPa.

2. The overall buckling load should not exceed the interframe buckling load by more than 5%.

3. The T-frame stiffeners should be sufficiently stocky to ensure that stiffener tripping does not occur.

4. The specimen diameter should be 1.0 m or less to readily fit within the available pressure test chamber.

Preliminary specimen sizing was determined based on the SSP 74 [1] design code. The preliminary design had to be revised due to the lack of availability of the plate material chosen for the preliminary design (i.e. 0.1875-inch HY80 plate). The material finally selected was 0.25-inch HY80 plate. To offset the use of thicker plate material, the specimen diameter was increased to 1.15 m, which is the maximum size that the testing apparatus can accommodate. A higher design collapse pressure of approximately 7 MPa had to be accepted as a result of these changes, which was approved by the project authority at DRDC.

Figure 2.1 identifies the key elements of the final specimen design:

1. The sizing of structural elements, including outer cylinder, stiffener webs and flanges, and the spacing of the stiffeners;

2. The detailing of the welds connecting the outer cylinder, web and flanges;

3. The sizing of the solid specimen end cap;

4. The sizing of the removable specimen end cap;

5. The sizing of the bolts for the removable end cap; and

6. The detailing of the cylinder to end cap connection.

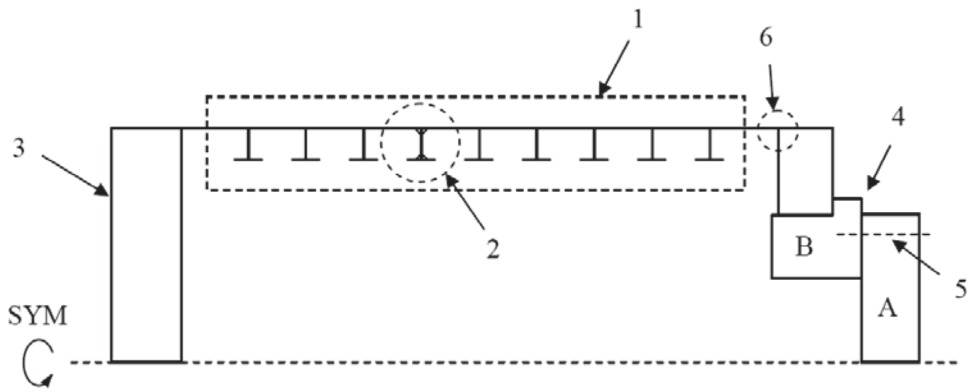


Figure 2.1: Cylinder specimen and design elements.

A copy of Martec's design notes detailing the final design calculations is included in Annex A.

2.2 Specimen Element Sizing

A spreadsheet incorporating the SSP 74 [1] design code, as developed by DRDC Atlantic, was checked for errors and used to obtain the final framing member sizes. Figure 2.2 shows the final size selection.

The overall buckling capacity was checked using a more accurate modelling technique that considered the effect of residual stresses and OOC. This method is outlined in Annex 6D of SSP 74 [1]. K79, a program written to implement this analysis technique, was obtained from DRDC Atlantic for this purpose.

To properly address residual stress effects, it is important to understand how the specimen was fabricated. Initially, it was decided that the cylinder would be constructed in four stages:

1. The external shell would be rolled to the correct diameter.

2. The web and flange elements would be welded together to form straight T-frames.

3. The T-frames would be rolled to the correct curvature.

4. The T-frames would be welded to the external shell.

The K79 analysis assumed that the T-frames and shell were rolled separately. Table 2.1 shows the computed buckling loads. The tabulated results indicate that the K79 buckling pressure was within 1% of the buckling pressure obtained from the SSP 74 spreadsheet.

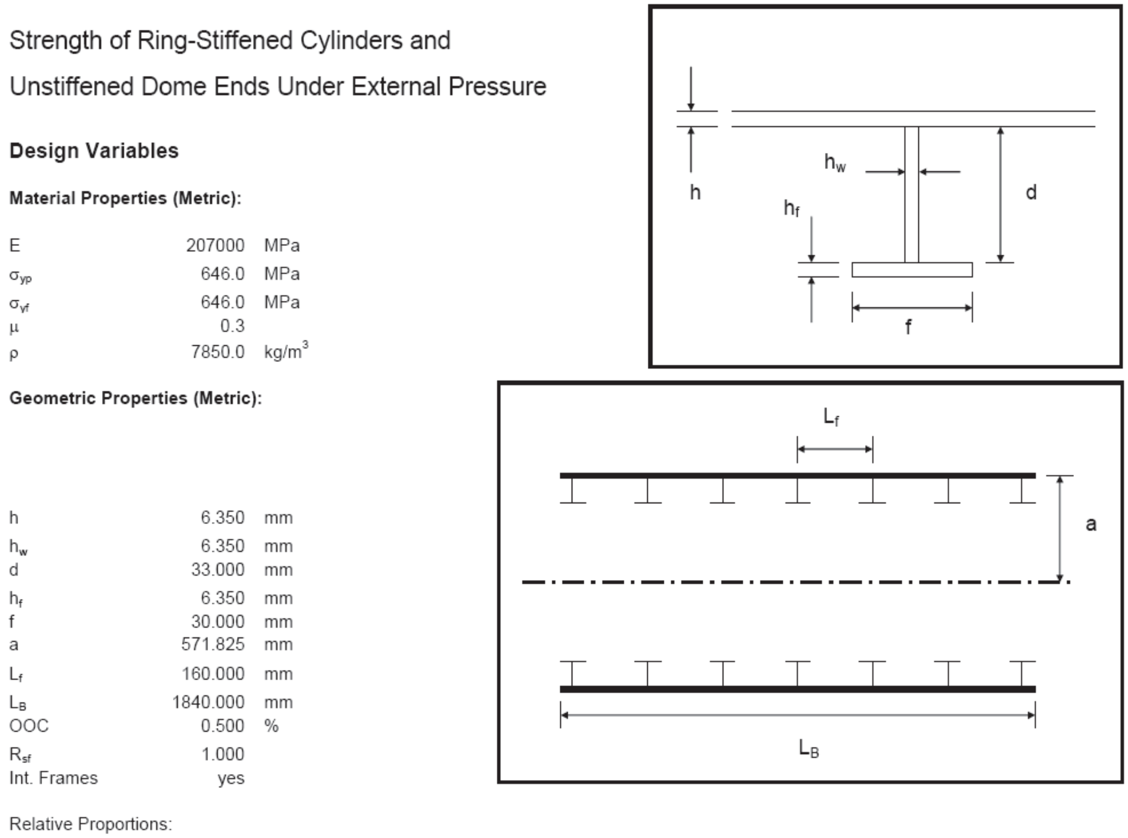


Figure 2.2: Specimen sizing.

Table 2.1: Buckling pressures for interframe and overall modes.

Buckling Mode	SSP 74 Spreadsheet	K79 Method
Interframe	6.798 MPa	–
Overall	7.028 MPa	7.078 MPa

It was determined that because the plate thickness was increased to 0.25 inches, the T-frames could not be rolled as one piece. It was therefore decided that it would be preferable to first fabricate the web elements in three 120° arc lengths, and then weld them together to obtain a circular web element. The flange plate element could then be rolled and welded to the web section. It is noted that the lack of web residual stresses resulting from this alternate fabrication sequence would be expected to result in an overall buckling pressure slightly higher than the values given in Table 2.1.

An additional finite element (FE) analysis was subsequently conducted by Martec using SubSAS and VAST following specimen fabrication. This analysis, which incorporated the as-fabricated geometry and material properties of the initial "baseline" test specimen, is discussed in Section 4.

2.3 Welds Connecting Specimen Elements

The welds joining the outer cylinder, web elements and flange elements were designed to transfer the full web shear capacity, assuming an effective width equal to the span between stiffeners. Fillet welds were used to weld the T-frame flange to the web and the web to the shell. Full penetration welds were used to join the web sections and were also used for the longitudinal shell seam weld. The CSA steel code CAN3-S16.1-01 [2] was used to establish appropriate base and weld metal strengths. A copy of the cylinder and end cap fabrication drawings is provided in Annex B. Additionally, the weld procedures used for joining HY80 to HY80 are included in Annex C.

2.4 End Cap Sizing

The end caps were designed to withstand a minimum pressure equal to two times the specimen collapse pressure. One solid end cap and one removable end cap were fabricated from 152.4-mm thick 350W mild steel. Those end caps were used for all three cylinder tests. The solid end cap consisted of a flat, circular plate, while the removable end cap had a large circular opening to allow access to the inside of the cylinder after end cap welding. The removable end cap also incorporated a cover plate with a face-seal arrangement to seal the circular opening for collapse testing. The end cap fabrication drawings are provided in Annex B.

To arrive at the required thickness of the solid end cap, it was idealized as a circular plate with pinned edges subject to external pressure loading. The maximum bending stress, which controls the thickness requirement, was computed using elastic thin-plate plate theory [3].

To reduce fabrication and material costs, the removable end cap was designed to include a thick insert piece fitted to the inner diameter of the circular opening, so that the material removed for the circular opening could be utilized as a cover plate. The insert was cut with a lip designed to rest against the outer face of the circular opening. The shear, bending and bearing capacities of the lip were checked using CSA S16.1-02 [4].

The potential for excessive prying forces acting on the bolts connecting the removable end cap components was checked using a simple FE model, wherein the removable end cap (labelled "A" in Figure 2.1) was assumed to be fixed at its exterior edge to the base end cap (labelled "B" in Figure 2.1). The gap was then determined, and the bolt strain was computed by dividing the gap size by the minimum bolt length.

2.5 Specimen to End Cap Connection

Preliminary FE analysis of the specimen end cap region revealed that high bending stresses would result if the cylinder was to be welded directly to the end cap. This is because the weld would restrain the cylinder wall from moving inward, causing large bending stresses to develop in the

cylindrical plate. This issue was compounded due to the difference in yield strength between the end cap and shell materials. Multiple options to reduce the tensile stresses were investigated, including the following:

1. overlapping the plates;

2. recessing the end cap to allow the cylinder to fit over top of the end cap; and

3. using a thicker QT100 shell insert with transition to cylinder.

While Option 2 was preferred for stress relief, the anticipated expense of cutting a cap recess, combined with potential fitting problems, made this choice unfeasible. Option 3 was selected over Option 1 due to ease of fabrication and because the insert material (QT100) has a higher yield strength than HY80. Several FE analyses were performed to optimize the tensile stress distribution at the cylinder-cap junction.

The specimen-to-end cap detail is included in the fabrication drawings in Annex B.

2.6 Design Review

International Submarine Engineering Research Ltd. ("ISER") reviewed Martec's design notes and conducted an independent check of the proposed specimen design using ABS rules [5]. ISER found no issues with the design approach or calculations as set out in the design notes. The collapse pressure predicted by ISER was within 5.9% of that predicted by Martec using SSP 74.

2.7 Fabrication Drawings

Fabrication drawings were prepared by Martec based on the final design parameters detailed above. The drawings specify the following:

- dimensions for the shell, T-frame stiffeners and end caps;
- sizing and type of welded joints;
- sizing and orientation of bolt holes and strain gauge connector ports; and
- face-seal arrangement for the removable end cap.

A copy of the cylinder and end cap fabrication drawings is provided in Annex B.

3 Specimen Fabrication

3.1 Overview

Petersen's Welding, located in Edmonton, Alberta, was contracted by C-FER to undertake the fabrication portion of the project. The company was responsible for fabricating the three test specimens and the associated specimen end caps. They also performed the machining required to simulate corrosion damage as well as the weld buttering repair.

3.2 Plate Material and Piece Layout

Three HY80 plates with nominal dimensions of 240 inches × 96 inches × 0.25 inches were purchased for the project. Each plate was obtained from the same heat, and mill certificates for each plate were provided by the vendor (see Annex D). For each test specimen, the shell plate, flanges, webs, coupon panel and spare material panel were taken from the same "parent" plate. The parent plate used to fabricate each specimen, by plate heat/lot-slab, is listed in Table 3.1.

Table 3.1: Parent plate used for specimen fabrication.

Specimen	Plate Heat – Slab
Specimen A	R2452-01AC
Specimen B	R2452-01AB
Specimen C	R2452-01AD

Each parent plate was cut into two pieces prior to shipping. One piece served as the source material for the shell and flange elements, while the other piece served as the source material for the web elements, coupon panel and spare material panel.

The shell, flanges, webs, coupon panel and spare plate for each specimen were waterjet cut from their parent plate pieces. Waterjet cutting was utilized to minimize the heat input and distortions resulting from the cutting process.

The shell and T-frame flange elements were laid out such that the hoop direction of both components matched after rolling.

Copies of the vendor cut and plate layout drawings are included in Annex E.

3.3 Specimen Fabrication

A cylinder fabrication procedure developed by Petersen's Welding was submitted and approved by DRDC Atlantic. The major elements of the fabrication procedure are listed below:

- The shell, flanges and QT100 stiffeners were cold rolled following waterjet cutting.

- For the T-frame stiffeners,
  - three 120° arc segments were tack welded together to form a complete circular web;
  - flanges and webs were then tack welded together;
  - groove welds between web pieces were completed; and
  - a fillet weld of the flange-web connection was completed.
- The first three completed T-frames underwent non-destructive examination (NDE).
- Once the NDE requirements were satisfied, the remaining T-frames were welded.
- The longitudinal seam of the outer shell was tack welded.
- The T-frames were welded into place inside the shell plate.
- The seam weld was completed as T-frames were welded in place.
- Grid markings were drawn on the outer surface of the cylinders (see Figure 3.1).
- The end caps were welded to the specimen ends.

The complete procedure for specimen fabrication is included in Annex F.

Figure 3.1: Specimen A – Baseline showing outer surface grid markings.

3.4 Additional Fabrication to Simulate Corrosion Damage

A 160-mm × 160-mm patch of material was removed from the outer shell surface to simulate wall loss due to corrosion. The targeted mean wall loss was 20% of the shell wall thickness. This wall thickness reduction was introduced in Specimen B – Damaged and Specimen C – Repaired.

The simulated corrosion patch was machined into the shell at a location equidistant between Stiffener Frames 5 and 6 with the patch centre oriented 180° from the seam weld.

The simulated corrosion patch was machined by mounting the cylinder on a lathe and using a spring-mounted cutter to remove the material. The cylinder was indexed about its longitudinal

axis, and the cutting tool was moved radially until the desired wall thickness reduction was achieved.

To achieve the desired longitudinal and circumferential dimensions of the area of reduced wall thickness, the tool was first incremented in the longitudinal direction until the desired length of the patch was reached. It was then returned to its original starting position, and the cylinder was rotated about its longitudinal axis by a fixed angular displacement. The tool was then incremented once again in the longitudinal direction. This process was continued until the desired metal loss extent was achieved. Leftover slivers of material between the longitudinal cuts were smoothed out using a buffing wheel.

After the area of reduced wall thickness was machined, a fine grid pattern was marked across the area to provide a reference for subsequent geometry surveys (see Figure 3.2).

Figure 3.2: Simulated corrosion patch on Specimen B – Damaged.

3.5 Additional Fabrication to Repair Damaged Region

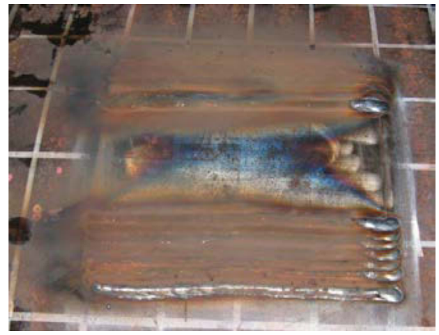
The simulated corrosion patch machined into the outer shell surface of Specimen C was “repaired” using weld buttering.

Weld buttering was carried out using a PGMAW welding process. Multiple side-to-side passes (28 in total) were applied across the area of reduced wall thickness until the built-up thickness was greater than the original thickness of the shell. The local plate temperature was monitored, and sufficient time between welding passes was taken to allow the material to air cool to within the maximum specified interpass temperature. The majority of weld passes took between 30 and 40 seconds to complete (with the longest being 51 seconds), and the voltage and amperage ranged from approximately 20.1 to 20.9 V and 100 to 115 A, respectively.

The weld passes were then manually blended into the surrounding shell material using a grinder/sander, and a fine grid pattern was marked onto the area to provide a reference for subsequent geometry surveys.

Figures 3.3 and 3.4 show the progression of the weld buttering process.

(a) Repair area following initial weld passes



(b) Repair area after additional weld passes

(c) Repair area before final blending

(d) Repair area after final blending

Figure 3.3: Progression of weld buttering.

Figure 3.4: Repaired region on Specimen C – Repaired.

It should be noted that there was visible "dishing" in the weld repaired area. This distortion was attributed to the heat input during the repair process. The extent of this distortion was captured in the geometry surveys detailed in Section 3.9.

3.6 NDE Program

Petersen's Welding supervised the execution of an NDE program that was developed, in consultation with DRDC Atlantic, to ensure that the approved weld procedures produce quality welds.

The required NDE program used surface inspection techniques (i.e. MPI or dye penetrant) to examine the fillet welds used to join the web sections and web-flange joint. NDE was carried out on the first three fabricated T-frames, prior to welding them to the shell plate, in accordance with ASME BPVC, Section IX [6].

The welds successfully passed the NDE inspection. A copy of the inspection report is included in Annex G.

3.7 Component Element Dimensional Tolerances

Dimensional tolerances were specified for various components of the test specimens.

The quality assurance/quality control (QA/QC) program was developed to verify that dimensional tolerances were met. For each cylinder, the QA/QC program consisted of the following:

- Each T-frame was measured at two locations: 90° and 270° (with respect to the seam weld). The following measurements were taken at each location: flange width, flange thickness, web thickness, web width, flange-web centring, and the angle between flange and web.
- After the T-frames were welded to the inside the shell plate, the interframe spacing, end bay spacing, and the angle between the shell and web (for each T-frame) were measured at two locations: 90° and 270° (with respect to the seam weld).

A summary of the dimensional tolerance measurements for each test specimen is provided in Table 3.2.

Table 3.2: Summary of dimensional tolerance measurements.

Specimen Component Dimension		Target Value	Measured Values		
			Specimen A	Specimen B	Specimen C
Frame Web Depth	Mean (mm)	33 ± 4	33.2	33.2	33.0
	Std. Dev. (mm)		0.6	0.5	0.6
	COV (%)		1.77	1.65	1.78
Frame Web Thickness[1]	Mean (mm)	(A) 6.71 ± 0.40 (B) 6.73 ± 0.40 (C) 6.80 ± 0.41	6.82	6.84	6.81
	Std. Dev. (mm)		0.1	0.1	0.1
	COV (%)		1.03	1.01	1.22
Frame Flange Width	Mean (mm)	30 ± 4	29.8	30.0	29.9
	Std. Dev. (mm)		0.6	0.6	0.6
	COV (%)		1.90	1.88	1.95
Frame Flange Thickness[1]	Mean (mm)	(A) 6.71 ± 0.40 (B) 6.73 ± 0.40 (C) 6.80 ± 0.41	6.79	6.82	6.83
	Std. Dev. (mm)		0.06	0.07	0.08
	COV (%)		0.95	0.95	1.13
Frame Web/Flange Centre	Mean (mm)	15 ± 2	15.0	15.3	15.4
	Std. Dev. (mm)		0.7	0.6	0.5
	COV (%)		4.87	4.23	3.54
Web/Flange Angle	Mean (deg.)	90 ± 5°	88.6	88.3	88.4
	Std. Dev. (deg.)		0.8	1.0	0.8
	COV (%)		0.95	1.11	0.96
Interframe Spacing	Mean (mm)	160 ± 4	160.2	159.6	159.9
	Std. Dev. (mm)		0.8	0.8	0.9
	COV (%)		0.0	0.0	0.0
Shell/Web Angle	Mean (deg.)	90 ± 5°	88.3	88.4	88.3
	Std. Dev. (deg.)		0.9	0.9	0.7
	COV (%)		0.97	1.06	0.76

[1] Mean plate thickness with specified tolerance (±6%) expressed in mm. Mean plate thickness determined from material certificate for corresponding specimen.

The measurements comply with the specified dimensional tolerances and were quite uniform, as indicated by the low COV (less that 2%), for all parameters.

The detailed dimensional tolerance check results are included in Annex H.

3.8 Fabricated Specimen Geometry and Residual Stress Surveys

Each test specimen was surveyed during various stages of fabrication to determine geometric and residual stress characteristics. Table 3.3 details the survey intervals.

Table 3.3: Geometric and residual stress survey schedules.

Fabrication Stage	Geometric Surveys			Residual Stress Surveys		
	Specimen A	Specimen B	Specimen C	Specimen A	Specimen B	Specimen C
After welding of the cold rolled plates and frames to form the ring-stiffened cylinder	X	X	X	X		
After application of simulated corrosion thinning		X	X		X	
After weld buttering			X			X

3.8.1 Geometric Surveys

The geometric surveys consisted of measuring the cylinder radius (to determine OOC) and shell plate thickness. Radius was measured using a Faro Laser Tracker™, which has an accuracy of ±0.0254 mm (0.001 inches). The OOC was characterized by measuring specimen radius at 36 circumferential locations, spaced at 10° radial arc intervals, along the cylinder length at each T-frame and mid-bay. Positive angles were referenced as clockwise with respect to End A on the specimen. A refined survey grid was used to better characterize the wall thickness and OOC in the vicinity of the corrosion damage/repair for Specimens B and C, respectively. The middle of the corrosion patch was aligned with 0° (180° from the seam weld) and centred between T-frames 5 and 6. The measurement grid is illustrated in Figure 3.5.

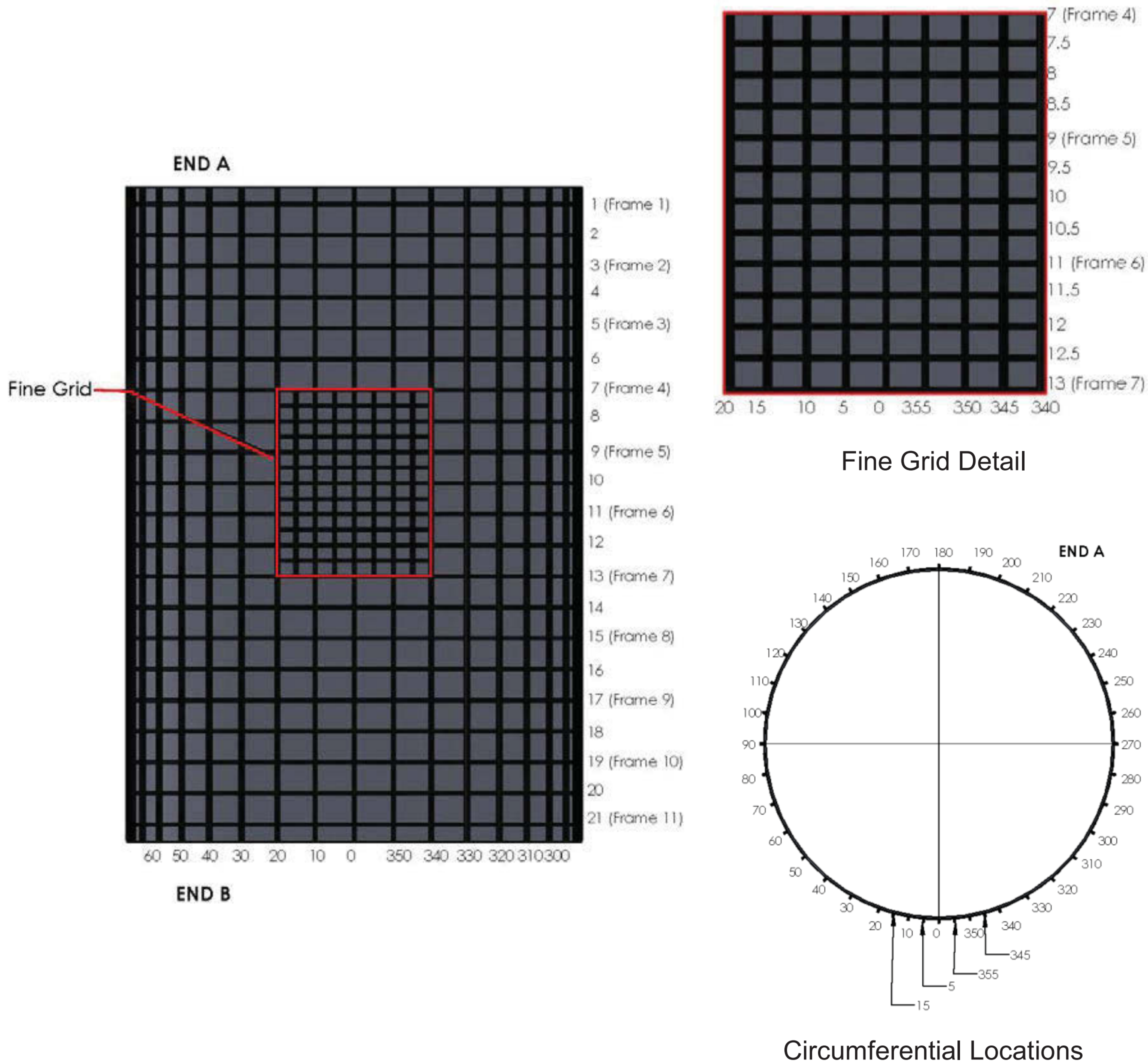


Figure 3.5: Geometric survey grid.

To determine OOC, the individual radius measurements were subtracted from those associated with a specimen-specific reference cylinder. The reference cylinder was determined by the Laser Tracker software, which effectively interpolated between best-fit circles as obtained from the survey measurement taken at each end of the specimen.

The OOC measurements for each cylinder, at each stage of fabrication, are listed in Tables 3.4 to 3.8. The tabulated maximum OOC was the largest absolute OOC value measured around the circumference at the specified longitudinal position.

Table 3.4: Geometric survey of Specimen A – Baseline, measurements taken after fabrication.

Measurement Position		Specimen A After Cylinder Formed			
		Mean Radius (mm)	Std. Dev. (mm)	Max. OOC (%)	Max. OOC Pos. (deg)
Frame 1	**Position 1**	575.36	1.71	0.65%	180
Mid-bay	**Position 2**	575.42	1.75	0.67%	180
Frame 2	**Position 3**	575.46	1.73	0.62%	180
Mid-bay	**Position 4**	575.37	1.81	0.68%	180
Frame 3	**Position 5**	575.80	1.78	0.69%	260
Mid-bay	**Position 6**	575.49	1.82	0.68%	250
Frame 4	**Position 7**	575.61	1.75	0.73%	250
Fine Grid	**Position 7.5**	574.13	0.31	0.20%	340
Mid-bay	**Position 8**	575.46	1.69	0.70%	250
Fine Grid	**Position 8.5**	574.22	0.28	0.20%	340
Frame 5	**Position 9***	575.75	1.76	0.77%	250
Fine Grid	**Position 9.5***	574.11	0.26	0.21%	340
Mid-bay	**Position 10***	575.46	1.75	0.69%	250
Fine Grid	**Position 10.5***	574.24	0.23	0.16%	0
Frame 6	**Position 11***	575.74	1.81	0.71%	250
Fine Grid	**Position 11.5**	574.23	0.22	0.16%	340
Mid-bay	**Position 12**	575.52	1.89	0.69%	250
Fine Grid	**Position 12.5**	574.19	0.20	0.17%	340
Frame 7	**Position 13**	575.66	1.95	0.72%	250
Mid-bay	**Position 14**	575.68	2.01	0.70%	250
Frame 8	**Position 15**	575.73	2.08	0.73%	250
Mid-bay	**Position 16**	575.63	2.18	0.79%	180
Frame 9	**Position 17**	575.65	2.21	0.80%	180
Mid-bay	**Position 18**	575.61	2.27	0.91%	180
Frame 10	**Position 19**	575.70	2.27	0.85%	180
Mid-bay	**Position 20**	575.71	2.27	0.88%	180
Frame 11	**Position 21**	575.81	2.12	0.80%	180

* Simulated corrosion patch area (not machined on this specimen but marked).

Table 3.5: Geometric survey of Specimen B – Damaged, measurements taken after simulated corrosion machining.

Measurement Position		Specimen B After Simulated Corrosion			
		Mean Radius (mm)	**Std. Dev. (mm)**	**Max. OOC (%)**	**Max. OOC Pos. (deg)**
Frame 1	**Position 1**	575.64	1.80	0.82%	180
Mid-bay	**Position 2**	575.61	1.76	0.78%	180
Frame 2	**Position 3**	575.83	1.61	0.61%	120
Mid-bay	**Position 4**	575.63	1.53	0.59%	180
Frame 3	**Position 5**	575.87	1.51	0.59%	120
Mid-bay	**Position 6**	575.67	1.41	0.56%	190
Frame 4	**Position 7**	575.87	1.38	0.53%	120
Fine Grid	**Position 7.5**	574.71	0.38	0.10%	15
Mid-bay	**Position 8**	575.62	1.30	0.55%	180
Fine Grid	**Position 8.5**	574.84	0.26	0.08%	5
Frame 5	**Position 9***	575.92	1.29	0.51%	250
Fine Grid	**Position 9.5***	574.52	0.81	0.27%	5
Mid-bay	**Position 10***	575.52	1.36	0.56%	180
Fine Grid	**Position 10.5***	574.48	0.78	0.28%	355
Frame 6	**Position 11***	575.82	1.27	0.56%	240
Fine Grid	**Position 11.5**	575.08	0.24	0.09%	20
Mid-bay	**Position 12**	575.71	1.06	0.47%	240
Fine Grid	**Position 12.5**	575.15	0.27	0.12%	20
Frame 7	**Position 13**	576.04	1.05	0.55%	240
Mid-bay	**Position 14**	575.91	1.06	0.48%	240
Frame 8	**Position 15**	576.00	1.12	0.51%	240
Mid-bay	**Position 16**	575.90	1.17	0.49%	230
Frame 9	**Position 17**	576.07	1.32	0.57%	240
Mid-bay	**Position 18**	575.81	1.37	0.53%	240
Frame 10	**Position 19**	575.96	1.47	0.56%	230
Mid-bay	**Position 20**	575.86	1.56	0.60%	230
Frame 11	**Position 21**	576.03	1.59	0.65%	230

* Simulated corrosion patch area.

Table 3.6: Geometric survey of Specimen C – Repaired, measurements taken after fabrication.

Measurement Position		Specimen C After Cylinder Formed			
		Mean Radius (mm)	**Std. Dev. (mm)**	**Max. OOC (%)**	**Max. OOC Pos. (deg)**
Frame 1	**Position 1**	575.88	2.30	1.01%	240
Mid-bay	**Position 2**	575.85	2.27	0.96%	240
Frame 2	**Position 3**	575.98	2.20	0.95%	240
Mid-bay	**Position 4**	575.87	2.19	0.89%	240
Frame 3	**Position 5**	575.92	2.03	0.83%	240
Mid-bay	**Position 6**	575.93	2.10	0.85%	240
Frame 4	**Position 7**	575.98	2.06	0.88%	240
Mid-bay	**Position 8**	575.88	2.10	0.85%	240
Frame 5	**Position 9**	576.13	2.02	0.90%	240
Mid-bay	**Position 10**	575.80	2.05	0.82%	240
Frame 6	**Position 11**	576.00	2.04	0.85%	240
Mid-bay	**Position 12**	575.83	2.12	0.81%	240
Frame 7	**Position 13**	575.90	1.98	0.76%	250
Mid-bay	**Position 14**	575.69	2.12	0.77%	180
Frame 8	**Position 15**	575.91	2.09	0.95%	180
Mid-bay	**Position 16**	575.56	2.17	0.88%	180
Frame 9	**Position 17**	575.69	2.04	0.71%	250
Mid-bay	**Position 18**	575.54	2.06	0.86%	180
Frame 10	**Position 19**	575.77	2.01	0.75%	180
Mid-bay	**Position 20**	575.61	2.10	0.95%	180
Frame 11	**Position 21**	575.67	1.97	0.83%	180

Table 3.7: Geometric survey of Specimen C – Repaired, measurements taken after simulated corrosion machining (fine grid only).

Measurement Position		Specimen C After Simulated Corrosion			
		Mean Radius (mm)	**Std. Dev. (mm)**	**Max. OOC (%)**	**Max. OOC Pos. (deg)**
Frame 4	**Position 7**	575.86	1.97	0.88%	240
Fine Grid	**Position 7.5**	574.46	0.15	0.13%	340
Mid-bay	**Position 8**	575.78	2.02	0.86%	240
Fine Grid	**Position 8.5**	574.56	0.12	0.12%	340
Frame 5	**Position 9***	575.89	2.05	0.90%	240
Fine Grid	**Position 9.5***	574.09	0.60	0.30%	355
Mid-bay	**Position 10***	575.61	2.06	0.82%	240
Fine Grid	**Position 10.5***	574.03	0.65	0.33%	355
Frame 6	**Position 11***	575.81	2.01	0.85%	240
Fine Grid	**Position 11.5**	574.43	0.10	0.13%	340
Mid-bay	**Position 12**	575.73	2.03	0.80%	240
Fine Grid	**Position 12.5**	574.43	0.08	0.12%	0
Frame 7	**Position 13**	575.79	1.92	0.77%	250

* Simulated corrosion patch area.

Table 3.8: Geometric survey of Specimen C – Repaired, measurements taken after weld buttering repair (fine grid only).

Measurement Position		Specimen C After Weld Buttering			
		Mean Radius (mm)	Std. Dev. (mm)	Max. OOC (%)	Max. OOC Pos.(deg)
Frame 4	**Position 7**	575.80	2.14	0.88%	240
Fine Grid	**Position 7.5**	574.05	0.14	0.19%	340
Mid-bay	**Position 8**	575.72	2.18	0.86%	240
Fine Grid	**Position 8.5**	573.80	0.16	0.23%	0
Frame 5	**Position 9***	575.72	2.40	0.90%	240
Fine Grid	**Position 9.5***	572.36	0.64	0.56%	5
Mid-bay	**Position 10***	575.17	2.69	0.82%	240
Fine Grid	**Position 10.5***	572.21	0.74	0.64%	5
Frame 6	**Position 11***	575.63	2.36	0.85%	240
Fine Grid	**Position 11.5**	573.75	0.12	0.25%	0
Mid-bay	**Position 12**	575.68	2.20	0.81%	240
Fine Grid	**Position 12.5**	574.04	0.07	0.18%	0
Frame 7	**Position 13**	575.74	2.08	0.79%	250

* Simulated corrosion patch area.

The effect of simulated corrosion machining and weld buttering on the geometry of Specimen C are shown in Figures 3.6 to 3.10. The figures show the variation in shell plate radius for a portion of the fine grid area through the complete manufacturing process. The fine grid spanned Positions 7 through 13, with the simulated corrosion patch spanning Positions 9 to 11. The fine grid extended over a circumferential arc length of 40° (from 20° to 340°), with the simulated corrosion patch extending from 7.5° to 352.5° (covering a 15° arc length).

Similar radial dimensions, before and after the introduction of simulated corrosion, were measured during the fabrication of Specimen B; however, due to software issues, the data after fabrication, but before simulated corrosion machining, was not retained. While the data for Specimen B is not available, note that it would be expected to be similar to that obtained from Specimens A or C.

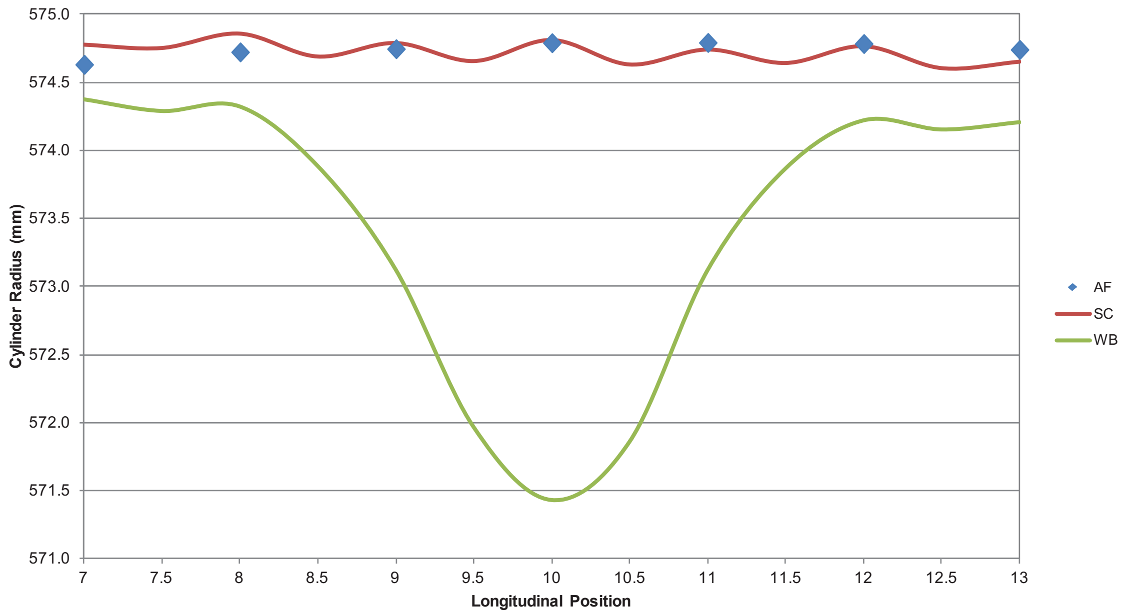


Figure 3.6: Specimen C – Repaired radius at the 10° position in the fine grid (AF: after fabrication, SC: simulated corrosion, WB: weld buttering).

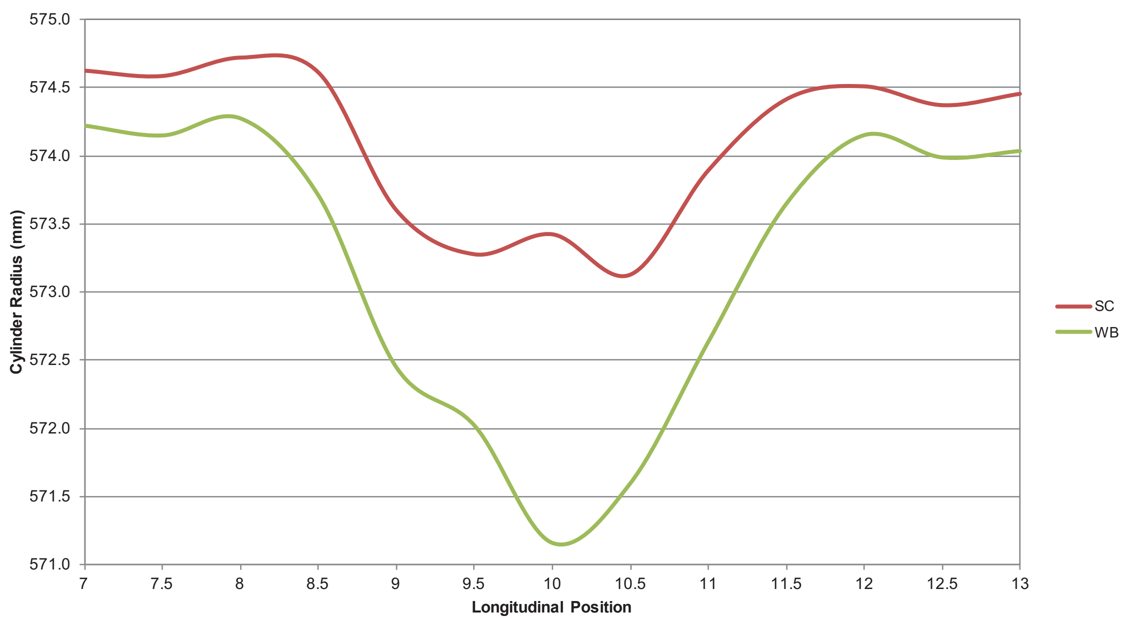


Figure 3.7: Specimen C – Repaired radius at the 5° position in the fine grid (SC: simulated corrosion, WB: weld buttering).

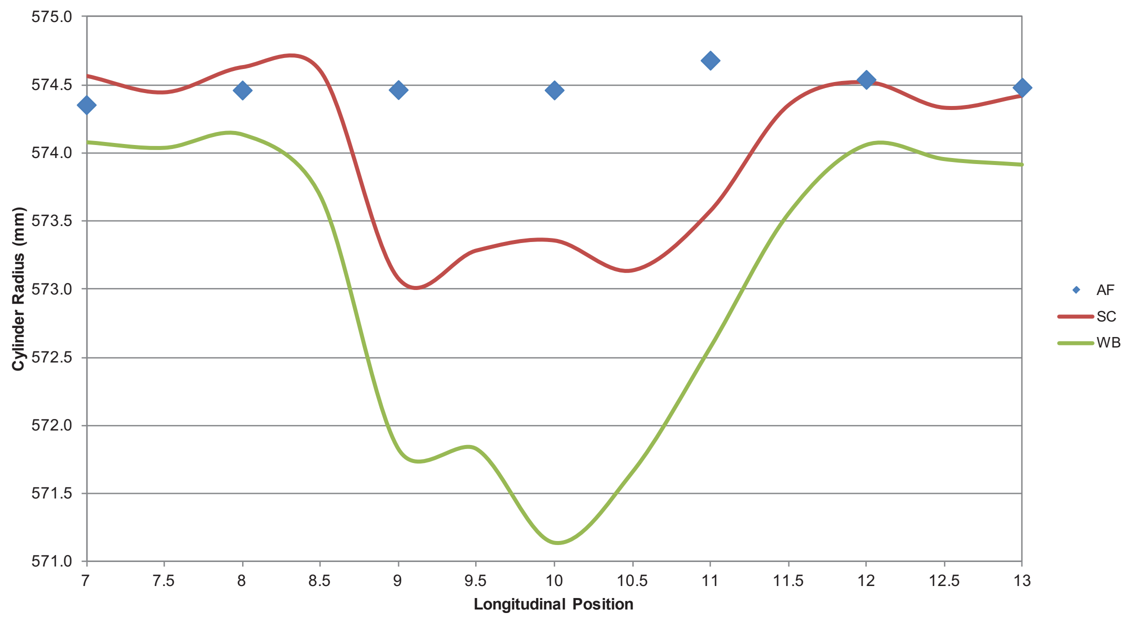


Figure 3.8: Specimen C – Repaired radius at the 0° position in the fine grid (AF: after fabrication, SC: simulated corrosion, WB: weld buttering).

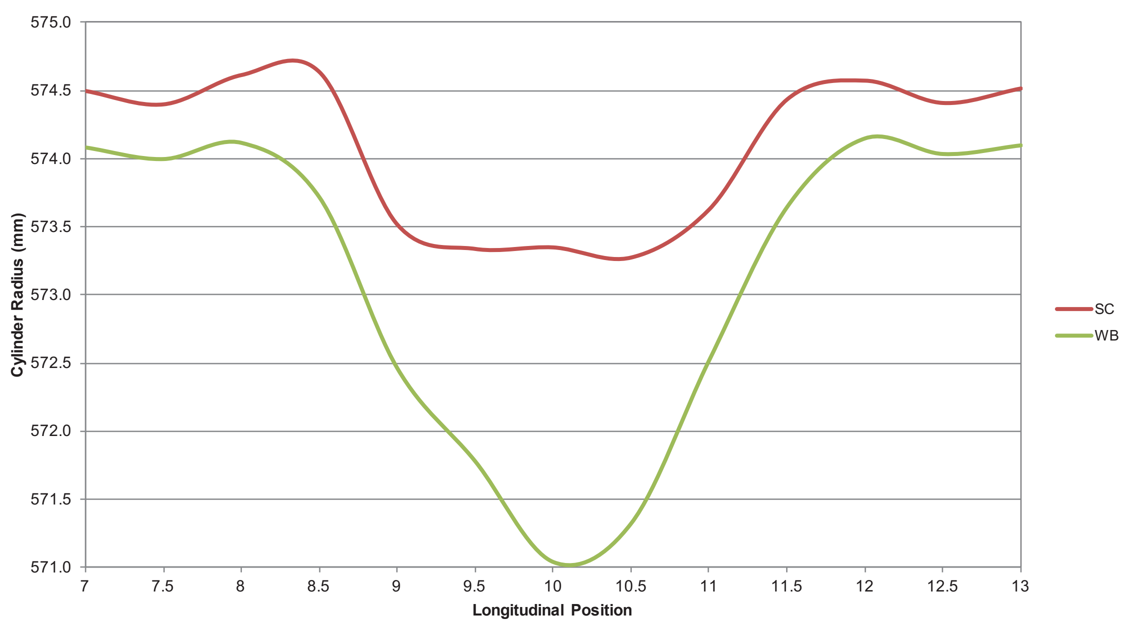


Figure 3.9: Specimen C – Repaired radius at the 355° position in the fine grid (SC: simulated corrosion, WB: weld buttering).

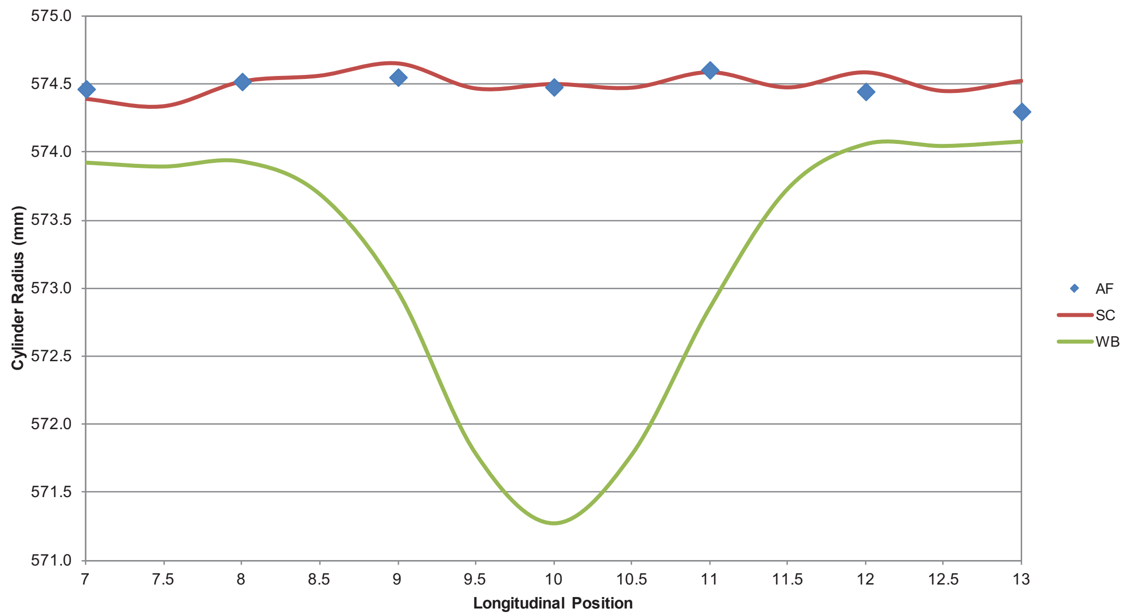


Figure 3.10: Specimen C – Repaired radius at the 350° position in the fine grid (AF: after fabrication, SC: simulated corrosion, WB: weld buttering).

The wall thickness reduction and corrosion patch contour are reflected in the radius profiles on the plots of the 5°, 0° and 355° positions (Figures 3.7, 3.8 and 3.9, respectively). The machining process that introduced the simulated corrosion did not significantly affect the radial dimensions of the shell plate beyond the extent of the corrosion patch area. However, the weld buttering did affect the shell plate radius beyond the corrosion patch as is evident in Figures 3.6 and 3.10. These locations were outside of the repair area; however, the radius deviated approximately 2.5 mm over the length of the fine grid, with the largest deviation observed between Frames 5 and 6. The relatively thin plating combined with the large amount of heat input, associated with weld buttering, likely caused the heat-affected zone to extend outside the buttered region, which led, in turn, to weld distortions outside the repaired area.

Wall thickness was measured using an ultrasonic probe with an accuracy of ±0.0254 mm (0.001 inches). The wall thickness profile was established by taking measurements from the same circumferential locations as the radius measurements but only from the mid-bay positions along the cylinder length. A summary of the wall thickness measurements is presented in Table 3.9, with the detailed measurements available in Annex I.

Table 3.9: Summary of geometric survey wall thickness measurements.

Cylinder	Plate Thickness[1]	Shell Thickness After Fabrication[2]			Shell Thickness in Damaged Region			Shell Thickness in Weld Buttering Region		
	Mean (mm)	Mean (mm)	Std. Dev. (mm)	COV (%)	Mean (mm)	Std. Dev. (mm)	COV (%)	Mean (mm)	Std. Dev. (mm)	COV (%)
Specimen A	6.71	6.79	0.11	1.59	-	-	-	-	-	-
Specimen B	6.73	6.76	0.05	0.69	5.50	0.10	1.78	-	-	-
Specimen C	6.80	6.58	0.16	2.39	5.52	0.05	0.94	8.09	0.36	4.42

[1] Mean value determined from material certificates.

[2] Does not include seam weld.

All of the wall thickness measurements, with the exception of the weld buttering region, were relatively uniform as indicated by the COV. The average shell thickness was within 3% of the mean plate thickness values. Wall loss from simulated corrosion machining was determined as the difference between the post-fabrication and damaged region values. The mean wall loss values in the simulated corrosion areas were 18.6% and 16.1% for Specimens B and C, respectively, which are just below the 20% target. Conversely, the mean wall thickness in repaired region was approximately 22.9% greater than the mean post-fabrication value.

3.8.2 Residual Stress Surveys

Residual stress surveys were conducted by DRDC Atlantic staff using a portable miniature X-ray diffractometer (mXRD).

4 Finite Element Predictive Collapse Load for Specimen A

4.1 Overview

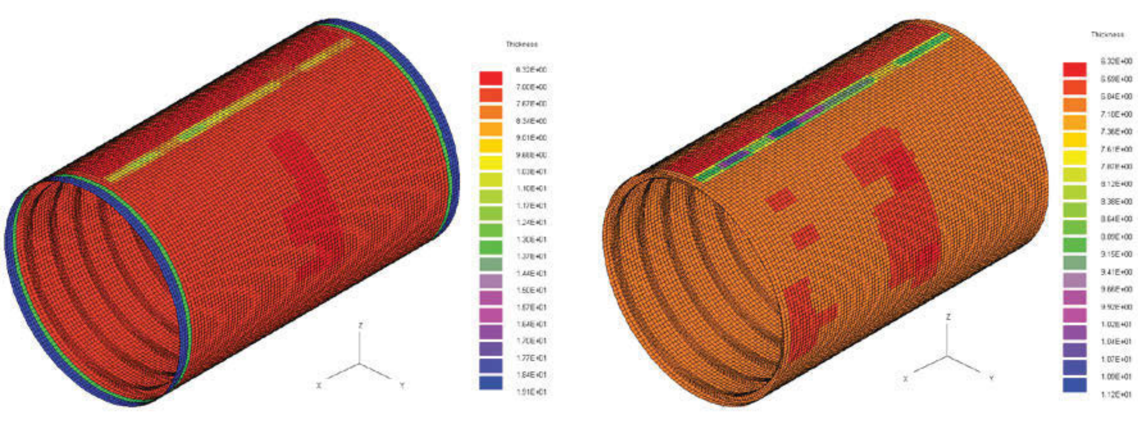
Two FE analyses were performed by Martec Limited using VAST and LS-DYNA FE codes. The models are identical in all aspects except for the element types and solution strategies. The models were generated using Martec's submarine structural modelling software, SubSAS, and were converted to VAST and LS-DYNA formats.

4.2 FE Model Geometry

The finite element model consisted of 32,580 four-node shell elements as shown in Figure 4.1. Eighty-one elements were used in the circumferential direction, with eight elements between frames. The frames were modelled using four-node shell elements, with four elements through the web and four elements across the flange.

Two types of measured imperfections [8] were mapped onto an initially perfect geometric model using SubSAS: thickness variations and OOC variations.

The shell plate thicknesses were mapped onto the FE model using the Voronoi thickness map option in SubSAS [9]. Frame element thickness measurements were not obtained, so the frame elements were assigned a constant thickness of 6.78 mm. Figure 4.1a shows the variation in element thickness for the entire specimen. Note that the shell ends have thicker plating to preclude bending overstress in that area. Figure 4.1b shows the thickness variation with the thick end plates removed. The figure indicates that there are thicker areas along the weld seam; this occurs because of the weld metal accumulation along the seam.

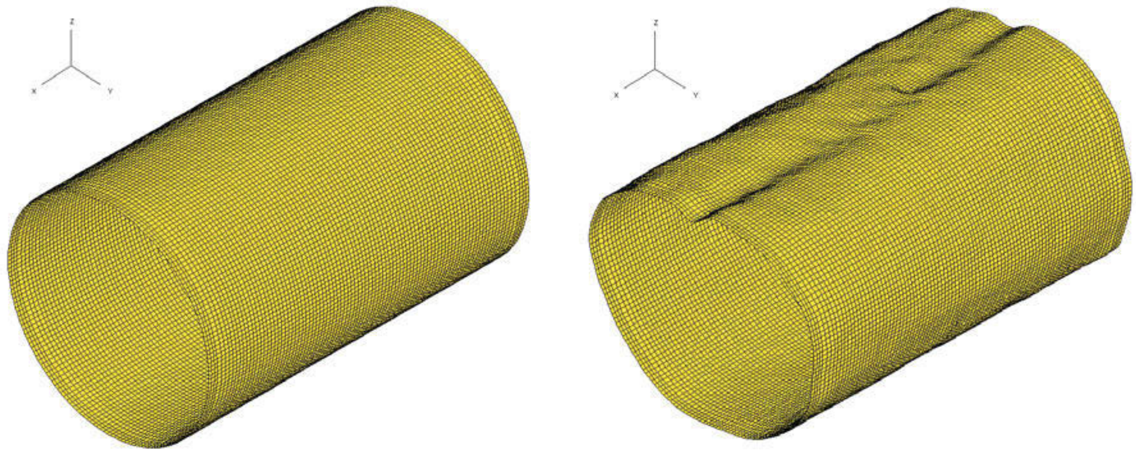


(a) Complete FE model

(b) FE model with thick end elements removed

Figure 4.1: Element thickness contours.

Figure 4.2 shows the OOC variations, which were mapped onto the FE model using the overall OOC mapping option in SubSAS [9]. The plate OOC variations were mapped to the frame elements directly since there were no measurements for these. It can be seen that there is a radial depression in the seam area. This is attributed to welding-induced distortion. The maximum measured OOC was on the order of 0.9%, which is higher than the 0.5% assumed in the original design calculations.



(a) Pristine model (b) OOC model – OOC magnification 25×

Figure 4.2: Element OOC plot.

4.3 Boundary Conditions and Loads

Figure 4.3 shows the loading and boundary conditions used in the model. To model the effects of the stiff 150-mm thick end plates, both ends were fully restrained against radial movement. To model the application of end cap pressure, one end was restrained to prevent x-axis displacement and the other end was allowed to translate in the x-direction. Radial pressures were applied over the outer shell plate and line loads corresponding to the applied end cap pressure were applied along the translating cylinder end.

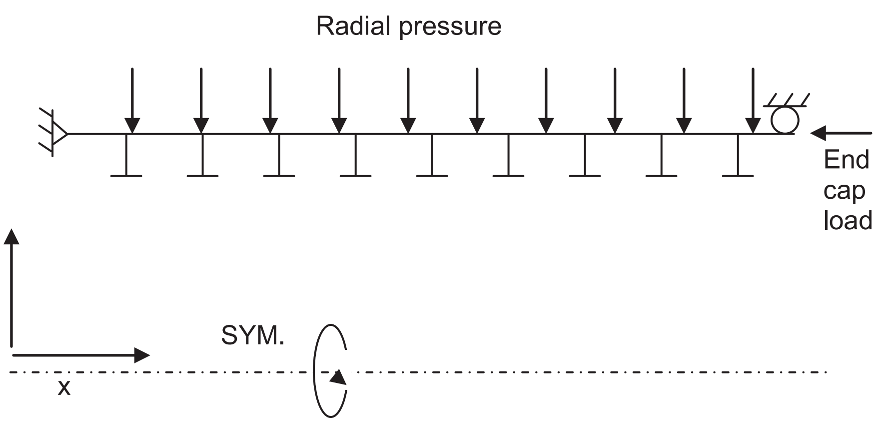


Figure 4.3: Boundary conditions and loads.

4.4 Material Properties

All elements were assigned nonlinear material properties using piece-wise linear stress-strain curves. The stress-strain curves for the cylinder plating and frame flanges are the so-called effective stress-strain curves, which include the effects of cold-bending residual stresses.

Cold-bending residual stresses were estimated using a simplified analytical model assuming an elastic-perfectly plastic material behaviour and an entirely elastic springback [10]. The over-bend radius was approximated using the following expression:

$$R_{ob} = \left[\frac{1}{R_{final}} + \frac{3\sigma_Y\left(1-\nu^2\right)}{tE} \right]^{-1} \tag{4.1}$$

where

R_{ob} = over-bend radius,

R_{final} = final radius after springback,

σ_Y = yield stress,

t = plate thickness,

E = elastic modulus, and

ν = Poisson's ratio.

Assuming a linear distribution of strain through the thickness of the element, the maximum strain at the cross-section after over-bending and just before the onset of springback is given by the following:

$$\varepsilon_{\max} = \kappa \frac{t}{2} = \frac{1}{R_{ob}} \frac{t}{2} \tag{4.2}$$

where

ε_{max} = maximum strain in the over-bend cross-section, and

κ = plate curvature.

The resulting stress distribution is estimated using an elastic-perfectly plastic idealization of the material behaviour as given by

$$\sigma = \begin{cases} \varepsilon E & if \ |\varepsilon| < \varepsilon_y \\ \sigma_Y & if \ |\varepsilon| > \varepsilon_y \end{cases} \tag{4.3}$$

where

ε_Y = yield strain.

The stress distribution above is used to determine the bending moment in the cross-section, which is also equal to the bending moment released during springback, M_{sb}. Assuming an entirely elastic springback, the equivalent elastic stress distribution is determined by classical beam theory, with the maximum springback stress given by

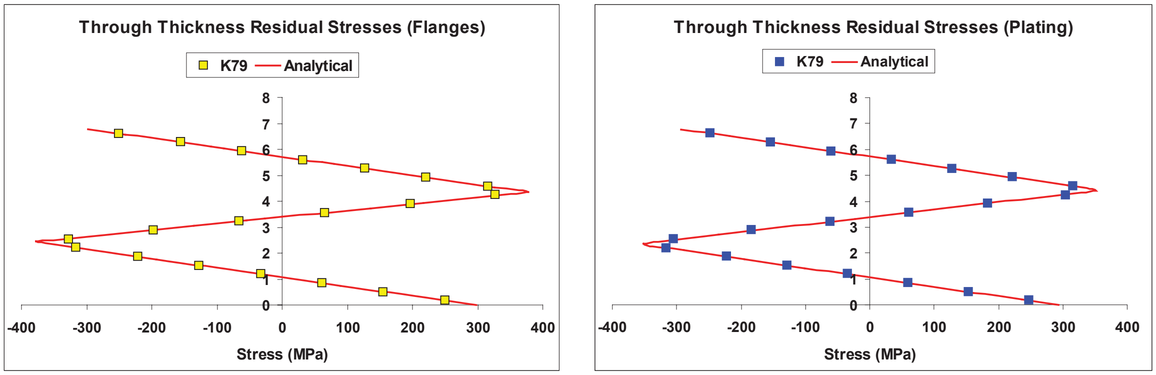
$$\sigma_{sb} = \frac{6M_{sb}}{t^2} \tag{4.4}$$

where

σ_{sb} = maximum springback stress, and

M_{sb} = springback bending moment.

Figure 4.4 shows the residual stress distributions in the shell plating and frame flanges after springback. Good agreement was observed between the analytical results and the results obtained from DRDC Atlantic's residual stress calculator, K79 [11].



(a) Cylinder plating

(b) Frame flanges

Figure 4.4: Cold-bending residual stress distribution.

The effective stress-strain curves were computed by applying increments of compressive strain to the cross-section, and then calculating the resulting stress on the cross-section using the following equation:

$$\sigma_{eff} = \frac{\sum_{i=1}^{N} \sigma_i A_i}{\sum_{i=1}^{N} A_i} \tag{4.5}$$

where

σ_{eff} = effective stress,

σ_i = compressive stress in i^{th} incremental area but not less than $-\sigma_y$, and

A_i = area of the i^{th} increment.

Figure 4.5 shows the stress-strain curves for the different specimen components. Unlike the shell plating and frame flanges, the frame webs were not cold-bent. Therefore, the frame web elements were assigned elastic-perfectly plastic material properties. The original design yield stress of 646 MPa was adjusted to 635 MPa [12], which was obtained from the tensile testing of the parent plate (see circumferential properties in Section 5.1.1)

The perfectly plastic portion of the stress-strain curve was maintained to a strain level of 2%. At this strain level, a hardening modulus was selected to achieve strain hardening to 1.5 times the yield stress at approximately 15% strain.

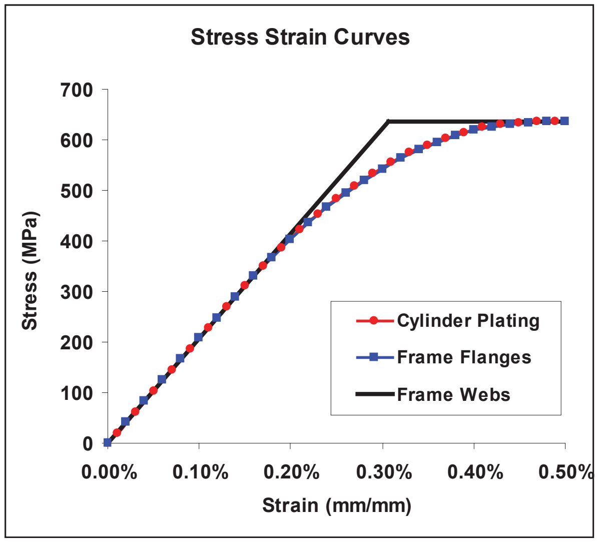


Figure 4.5: Material stress-strain curves.

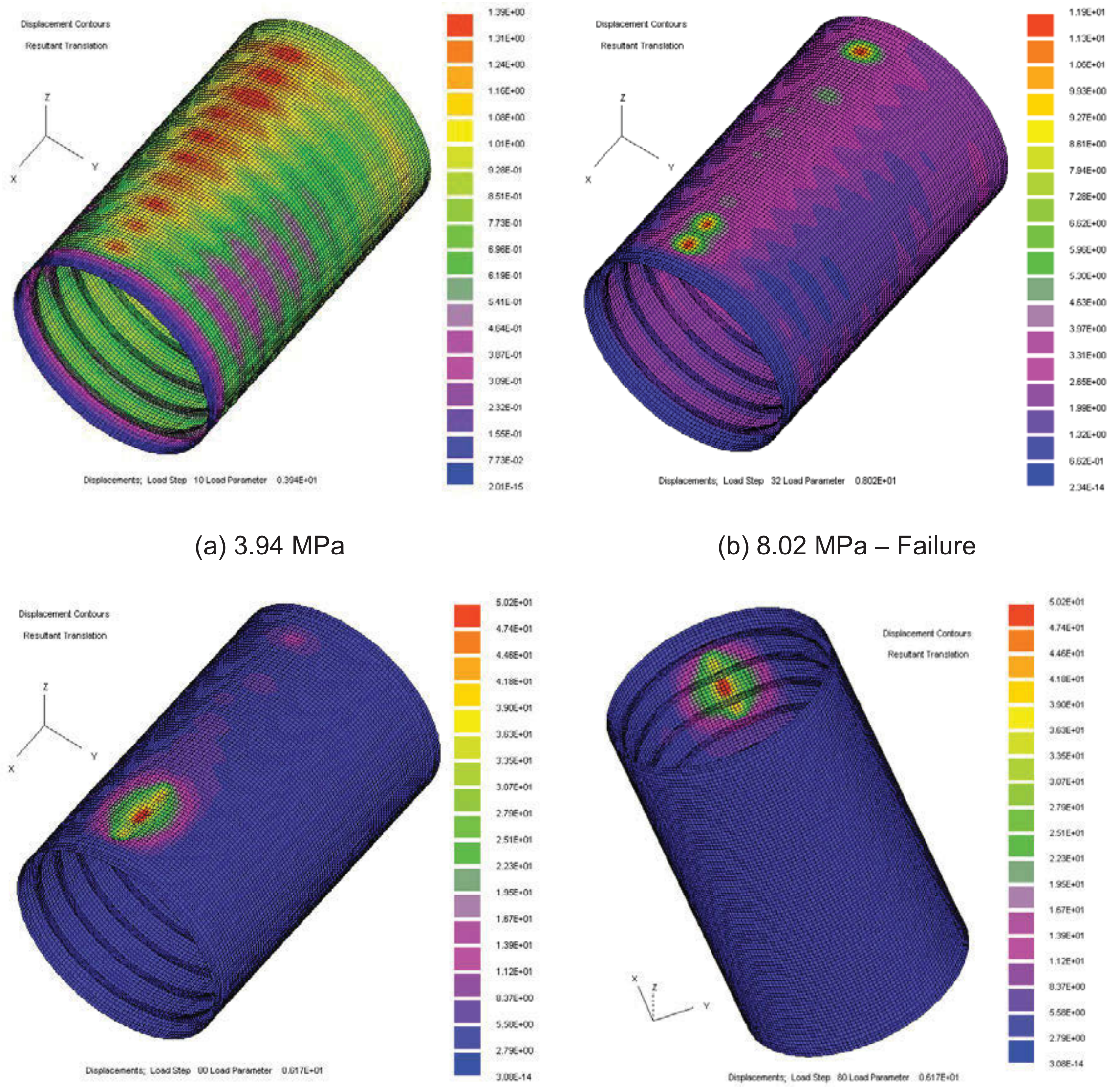
4.5 Solution Techniques

The finite element analysis in VAST was performed using the nonlinear geometry and material option [13]. Because the load decreases with increasing deformation for post-peak analysis, the solution was obtained using the orthogonal trajectory (arc length) method. The solution consisted of 80 load increments, with an initial load increment of 0.4 MPa. VAST adjusted the size of the load increment as required to ensure convergence.

The BFGS method with arc-length [14] was used for the LS-DYNA analysis. Automatic time stepping was used to ensure convergence.

4.6 FE Results

Figure 4.6 shows contours of resultant displacement on the outer shell for the VAST analysis. At 3.94 MPa (Figure 4.6a), the largest displacements occur in the vicinity of the weld seam. At the failure load of 8.02 MPa (Figure 4.6b), localized deformation patterns begin to form near the ends, with the largest displacements occurring between the first and third frames from the fixed end, and the first and second frames from the loaded end. The plot at the post-peak load (Figure 4.6c) shows that failure occurs between the first and third frames from the fixed end. Figure 4.6d shows significant stiffener deformations at 6.17 MPa, indicating that the deformation mode is not interframe, but rather of the overall buckling type. An interframe buckling mode would be characterized by alternating bulges in the plates between frames.



(a) 3.94 MPa

(b) 8.02 MPa – Failure

(c) 6.17 MPa – post-peak

(d) Post-peak stiffener plot

Figure 4.6: Resultant displacement contour plots – VAST analysis.

Figures 4.7 to 4.10 are LS-DYNA resultant displacement plots. From the examination of Figures 4.8 and 4.9, it is evident that the failure location is different from that of the VAST analysis. The failure is shown to occur between the third and fifth frame from the loaded end near the weld seam. The displacements in Figure 4.9 indicate that the failure mode includes a significant interframe buckling component as evidenced by alternating plate bulges. Figure 4.9 shows the stiffener deflections in the failure region. It is clear that there is significant stiffener deformation, indicating that the failure mode includes overall buckling characteristics. The failure mode thus appears to be of a mixed mode.

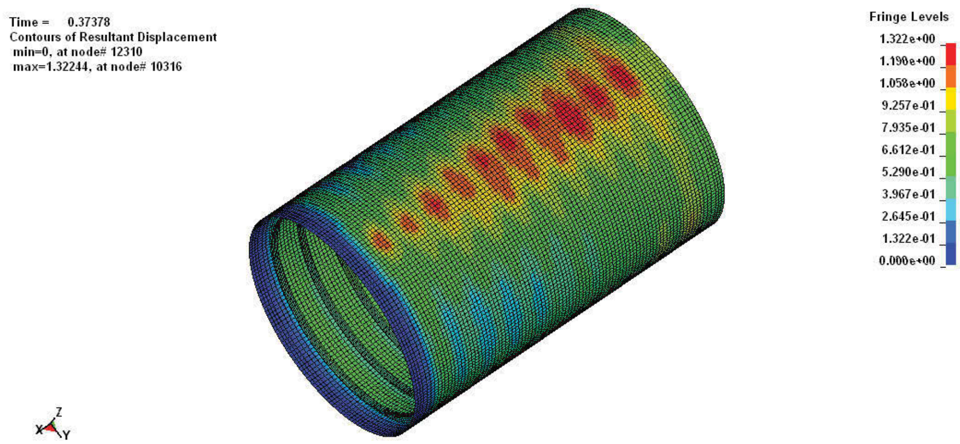


Figure 4.7: LS-DYNA displacement plot – 3.73 MPa.

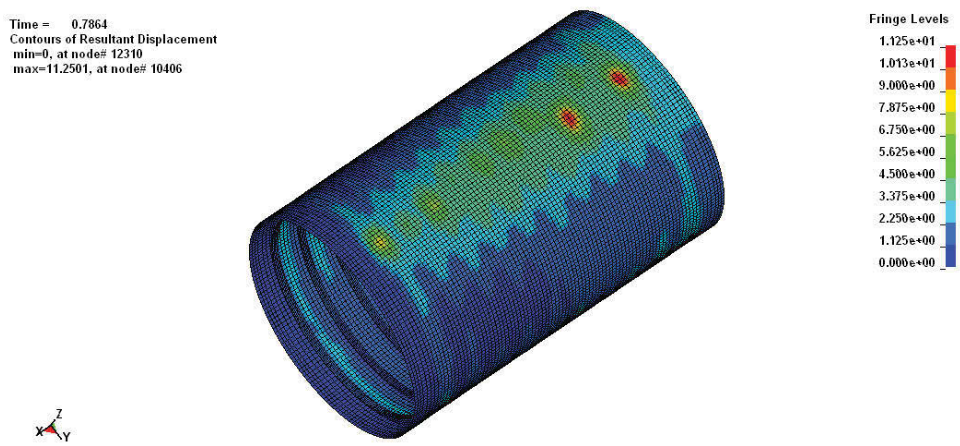


Figure 4.8: LS-DYNA displacement plot – 7.86 MPa (failure).

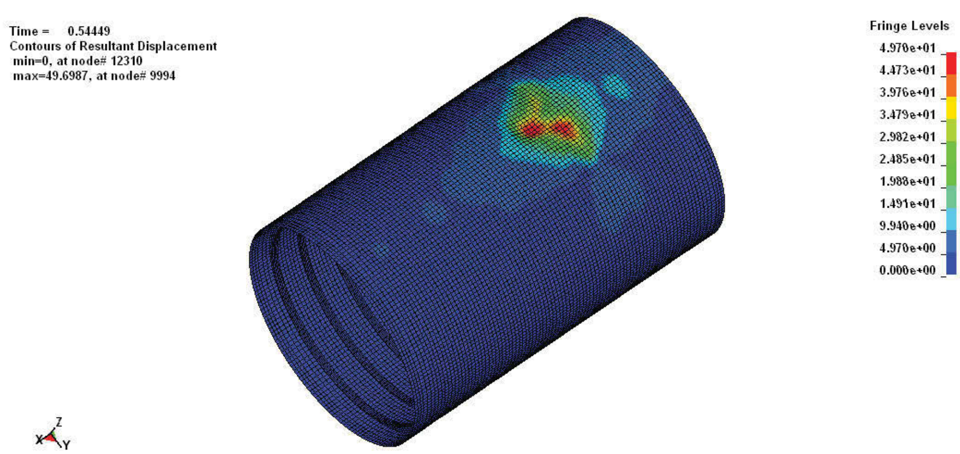


Figure 4.9: LS-DYNA displacement plot – 5.44 MPa (post-peak).

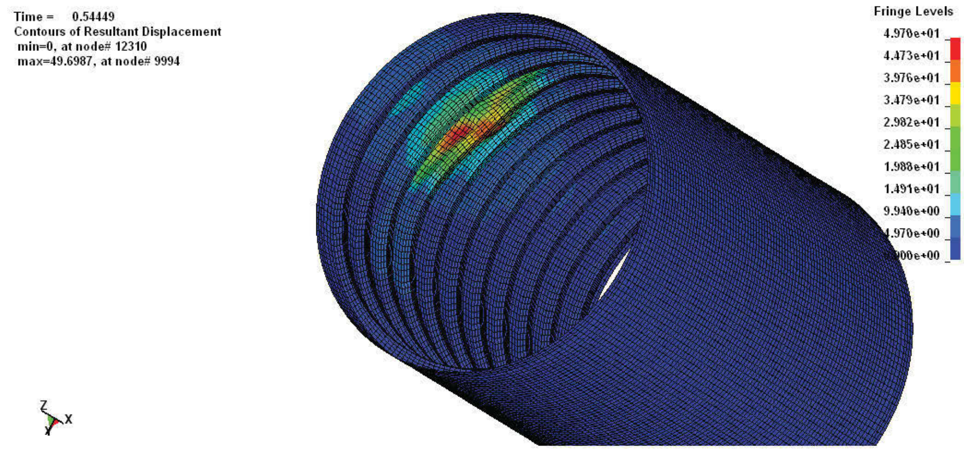
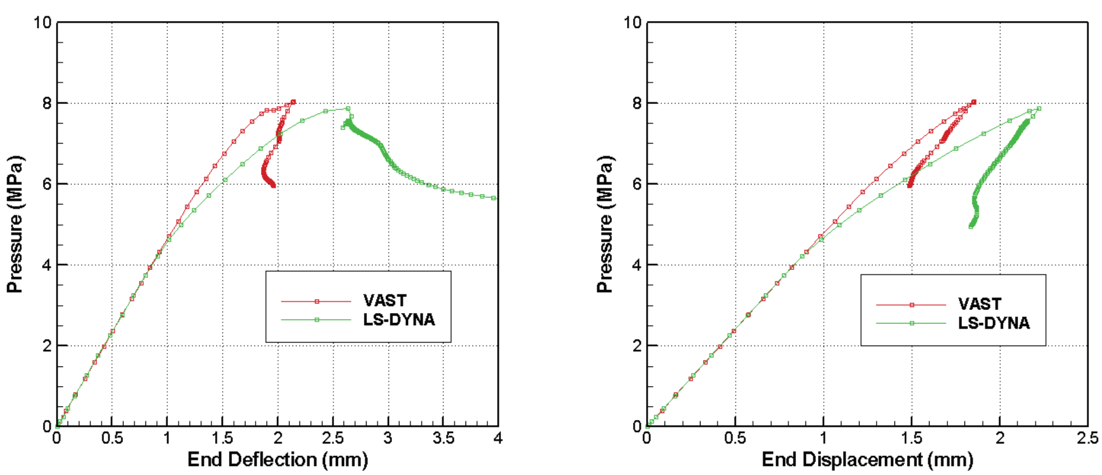


Figure 4.10: LS-DYNA displacement plot – post-peak stiffener.

Figures 4.11a and 4.11b show the load versus shortening curves for nodes 10591 and 1440, located at the cylinder end at 0° and 180° from the seam weld, respectively. The structural response obtained from both models is nearly identical up to a load of 4.1 MPa. At higher loads, the LS-DYNA analysis appears to exhibit a more flexible response than the VAST analysis. Since the failure locations are different for the two analyses, the load versus shortening response would not be expected to be identical.



(a) 0°from seam

(b) 180° from seam

Figure 4.11: Load shortening curves for FE analyses.

There are a number of model differences between the VAST and LS-DYNA analyses (such as the shell element formulation, and the convergence criteria and determination) that could account for

the differences in results. Regardless, the failure loads are within 2%, and the failure prediction is along the weld seam for both FE codes.

An additional analysis consideration involves initial imperfections. The imperfections incorporated in the analyses above were obtained before the specimen end caps were welded into place. End cap welding could alter the imperfection pattern and thereby potentially the failure load and mode. These effects were not reflected in the analyses.

5 Test Results

5.1 Coupon Testing

5.1.1 Overview

Coupon testing was conducted to determine the yield strength, tensile strength, Young's modulus and Poisson's ratio of the HY80 parent plate material. Coupons were taken from the plates in the directions corresponding to the longitudinal and hoop directions on the fabricated specimens. Three coupons from each orientation were tested from the plate used to fabricate Specimen A. One coupon from each direction was tested from the plate material used to fabricate Specimens B and C.

A 50.8-mm (2-inch) gauge length extensometer was attached to each coupon to determine Young's modulus, yield strength and tensile strength. A displacement rate of 0.23 mm/min (0.009 in/min) was used until the load started to drop, at which point the test was paused, the extensometer was removed and the test was resumed at an increased rate of 2.3 mm/min (0.09 in/min). Nominal coupons dimensions are detailed in Figure 5.1 below.

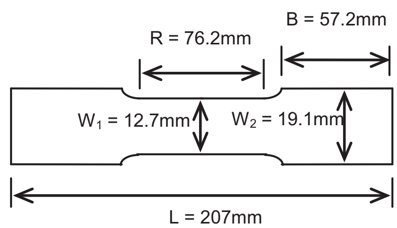


Figure 5.1: Nominal tension coupon dimensions.

Young's modulus for each coupon was determined by averaging the results from three load cycles wherein the coupon was loaded to 26.7 kN (6,000 lb), within the proportional limit, and then unloaded to near zero load. Young's modulus from each load cycle was determined using the method of least squares as specified in ASTM E111 [15].

Yield strength was determined using the 0.2% offset method as outlined in ASTM E8 [16], and tensile strength corresponded to the highest stress value achieved during testing.

Poisson's ratio was calculated as outlined in ASTM E132 [17]. In addition to the extensometer, biaxial strain gauges were affixed onto both sides of the coupon to determine the negative ratio of transverse to longitudinal strain in the elastic region.

The complete coupon test procedure and drawings are included in Annex J.

5.1.2 Coupon Test Results

A summary of the test results are provided in Tables 5.1 to 5.3 and Figures 5.2 and 5.3. Detailed coupon test results are included in Annex K.

Table 5.1: Longitudinal direction coupon test results.

Specimen/Coupon ID	Yield Strength, 0.2% Offset (MPa)	Tensile Strength (MPa)	Young's Modulus (GPa)
Specimen A			
- P1L1	644	719	209
- P1L2	645	717	197
- P1L3	644	717	195
- Mean	644	718	200
Specimen B			
- P2L1	638	718	204
Specimen C			
- P3L1	635	720	205

Table 5.2: Circumferential direction coupon test results.

Specimen/Coupon ID	Yield Strength, 0.2% Offset (MPa)	Tensile Strength (MPa)	Young's Modulus (GPa)
Specimen A			
- P1C2	634	720	194
- P1C3	637	722	204
- P1C4	635	721	198
- Mean	635	721	199
Specimen B			
- P2C2	632	717	199
Specimen C			
- P3C2	634	720	203

Table 5.3: Coupon test results for Poisson's Ratio.

Specimen/Coupon ID	Poisson's Ratio
Specimen A - P1C1	0.279
Specimen B - P2C1	0.279
Specimen C - P3C1	0.276

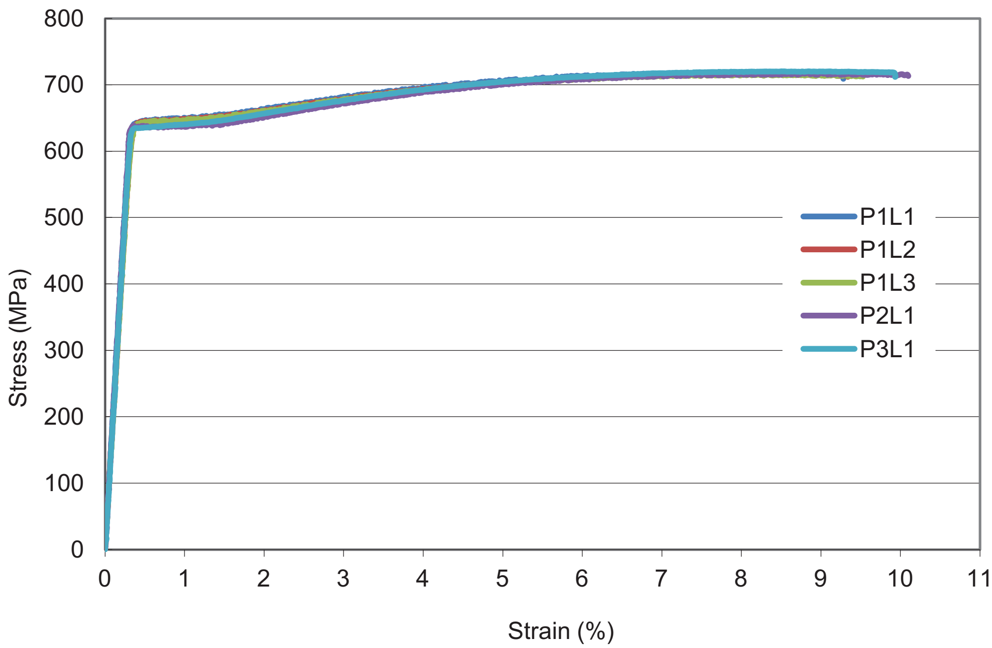


Figure 5.2: Stress vs. strain curves for axial direction coupon test results.

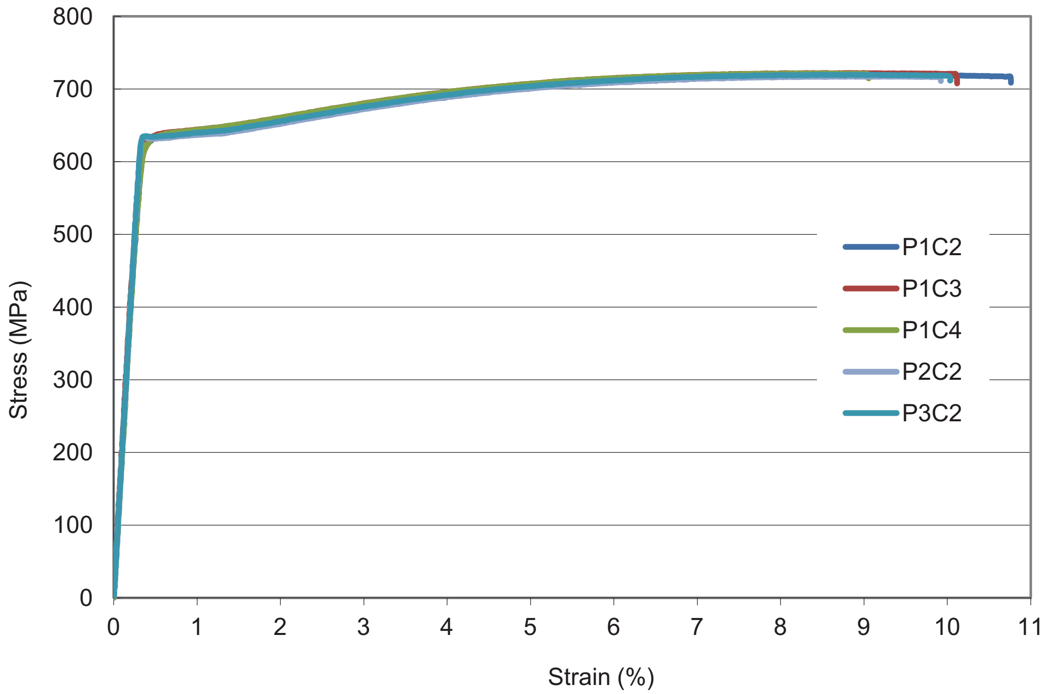


Figure 5.3: Stress vs. strain curves for hoop direction coupon test results.

The results show good agreement between the material properties obtained from each parent plate. Additionally, there is good agreement between the strength properties obtained in each direction (i.e. longitudinal and circumferential), indicating that the isotropic nature of the material was retained following plate forming.

5.2 Collapse Testing

5.2.1 Deepwater Experimental Chamber

C-FER's Deepwater Experimental Chamber (DEC; see Figures 5.4 and 5.5) was used for the collapse testing. The chamber has a tested pressure capacity of 62 MPa, with an inside diameter of 1.22 m and an overall inside length of 10.3 m. The DEC was used in conjunction with state-of-the-art computer hardware, software and signal conditioning equipment to control and monitor each test.

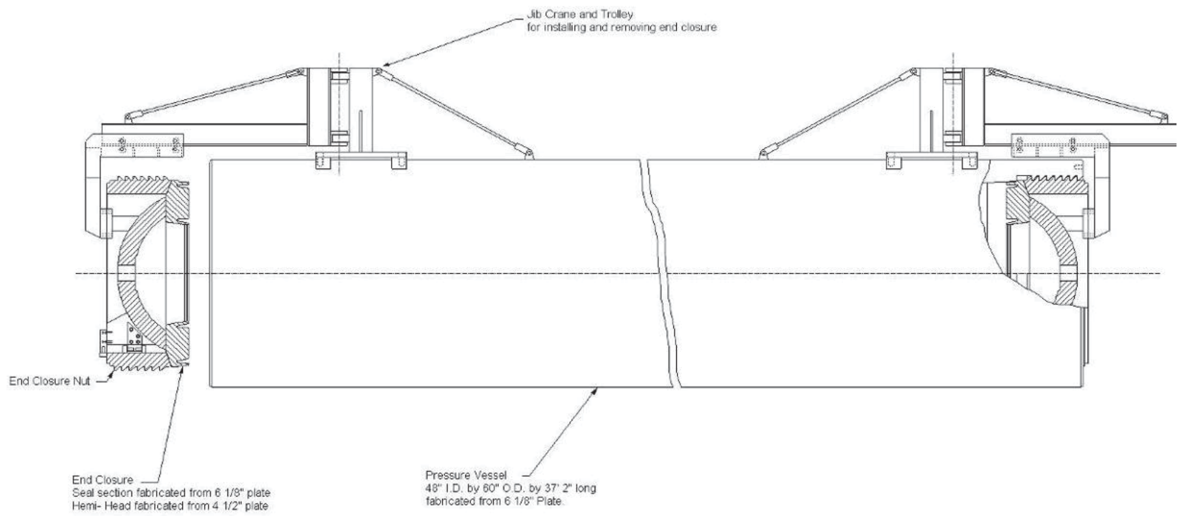


Figure 5.4: Schematic of C-FER's deepwater experimental chamber.

Figure 5.5: Photograph of C-FER's deepwater experimental chamber.

5.2.2 Instrumentation and Test Procedure

DRDC Atlantic provided C-FER with an instrumentation plan for each specimen, which clearly defined the type, location and naming convention for all of the applied strain gauges. This instrumentation plan is included in Annex L.

For Specimen A, 12 internally located uniaxial gauges, oriented in the circumferential direction, were placed on the flange of T-frame 6 and spaced at 30° arc length intervals. Additional circumferentially oriented uniaxial gauges were placed on each of the other T-frame flanges at 0°. External biaxial strain gauges were affixed to the shell mid-bay between T-frames 1 and 2 and T-frames 10 and 11, spaced at 60° arc length intervals and aligned in the longitudinal and circumferential directions. An additional 24 biaxial gauges were placed mid-bay between T-frames 5 and 6, spaced 15° apart and aligned with the longitudinal and circumferential directions.

For Specimens B and C, 12 internally located uniaxial gauges, oriented in the circumferential direction, were placed on the flange of T-frame 6 at 30°, 15° and 345° arc length intervals. Circumferentially oriented uniaxial gauges were also placed on each of the other T-frame flanges at 0°. Seven rosette gauges and two internally located biaxial gauges were placed mid-bay between T-frames 5 and 6, which were also mirrored on the external shell surface. Additionally, a single biaxial gauge was placed between T-frames 4 and 5 and oriented at 0°. Eleven externally located biaxial gauges were oriented in 30° arc length increments between 30° and 330°, mid-bay between T-frames 5 and 6. Two additional gauges were located on the outside shell surface, mid-bay between T-frames 5 and 6 and oriented at 15° and 345°, respectively.

Two pressure transducers (with ±0.05% accuracy) were used to monitor the collapse tests: one to monitor the externally applied (DEC) pressure and a second to monitor the internal specimen pressure. Figure 5.6 shows the arrangement in the DEC. For the test on Specimen A, 2,000-psi transducers were used to monitor both the DEC pressure and internal specimen pressure. For the tests on Specimens B and C, a 5,000-psi transducer was used to monitor the DEC pressure and a 2,000-psi transducer was used to monitor the internal specimen pressure.

All strain gauge and pressure data was recorded at a read rate of 100 Hz.

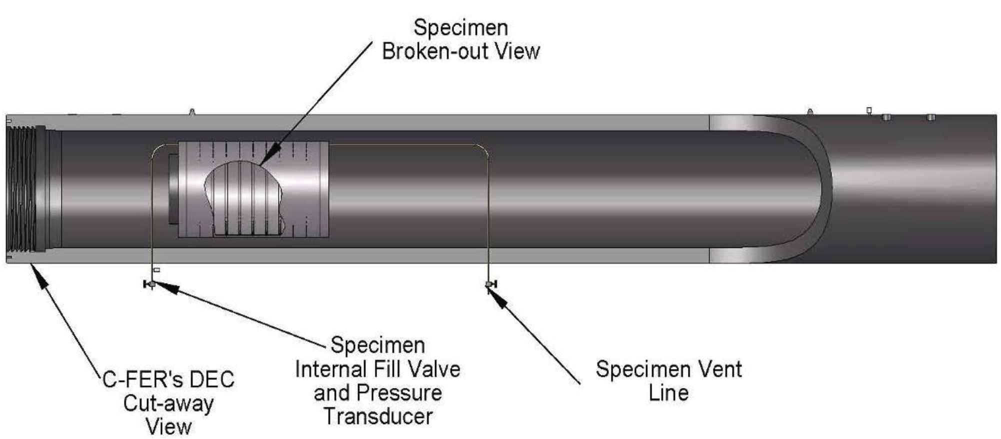


Figure 5.6: Collapse testing schematic.

Inside the DEC, the specimen rested on the bottom of the vessel, supported by a pair of "tabs" that were welded onto each end cap, so the cylinder wall was not in contact with the vessel wall.

The general test procedure involved simultaneously elevating the specimen internal and external pressure, and then loading the specimen, with net external pressure, by slowly releasing the specimen internal pressure. With the specimen vent valve closed, the DEC and specimen were pressurized simultaneously while keeping the differential pressure to a minimum. Once the DEC pressure reached 6.89 MPa (1,000 psi), the pump was stopped and the vessel was visually inspected for leaks. After this leak inspection, testing was resumed, and the DEC and specimen were pressurized until they reached a pressure greater than the predicted collapse pressure but not greater than 2,000 psi. The pump was then stopped, and the DEC and specimen were isolated. The specimen internal pressure vent valve was opened and water was allowed to bleed out at a controlled rate until specimen collapse occurred.

A detailed test procedure was prepared for DRDC Atlantic's review prior to testing and is available in Annex M.

5.2.3 Collapse Test Results

5.2.3.1 Specimen A – Baseline

Specimen A collapsed at a net differential pressure of 7.75 MPa. Following testing, the specimen displayed multiple permanent buckles, primarily located between T-frames 5, 6 and 7 and extending between approximately 75° and 225° (i.e. 75° CW and 135° CCW with respect to 0° from End A of the cylinder).

The post-collapse photos (Figure 5.7) and strain gauge data (Figures 5.8 to 5.15) indicate that the failure mode was interframe collapse. It should be noted that failed strain gauges are not included in the figures.

The onset of yielding of the shell plating and T-frames, which occurred well before specimen collapse, was determined using the procedure developed by MacKay [18]. Using this approach, yielding is assumed to occur if the calculated equivalent von Mises stress reaches the yield strength as determined from tensile coupon tests on the parent material. In determining the equivalent von Mises stress, it was assumed that membrane shear stresses are negligible and thus the longitudinal and circumferential stresses, as determined from the corresponding strain measurements, are effectively principal stresses.

Based on the above procedure, initial yielding in the outer shell plate was estimated to have occurred mid-bay between T-frames 10 and 11 at 0° at approximately 69% of the collapse pressure. However, subsequent shell plate yielding was concentrated mid-bay between T-frames 5 and 6 at 15° and 270°, which exceeded the yield strength almost simultaneously at approximately 74% of collapse pressure. By the onset of collapse, the majority of the stresses calculated from the shell mid-bay strain gauges exceeded the yield strength.

Pre-collapse T-frame yielding was evident at approximately 93% of the collapse load on T-frame 6 at 240°. Subsequent T-frame yielding was exclusively post-collapse.

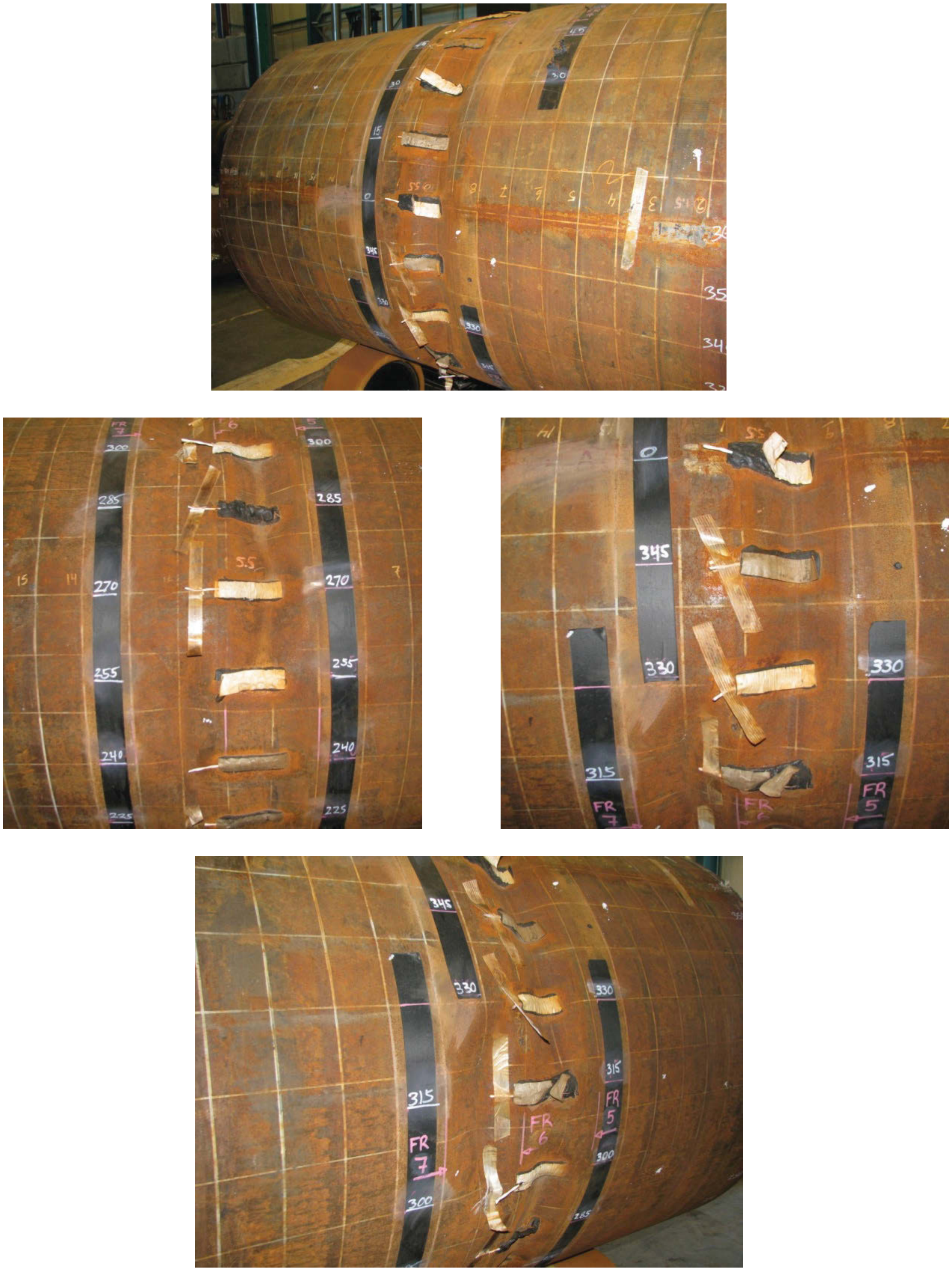


Figure 5.7: Post-collapse buckled configuration of Specimen A – Baseline.

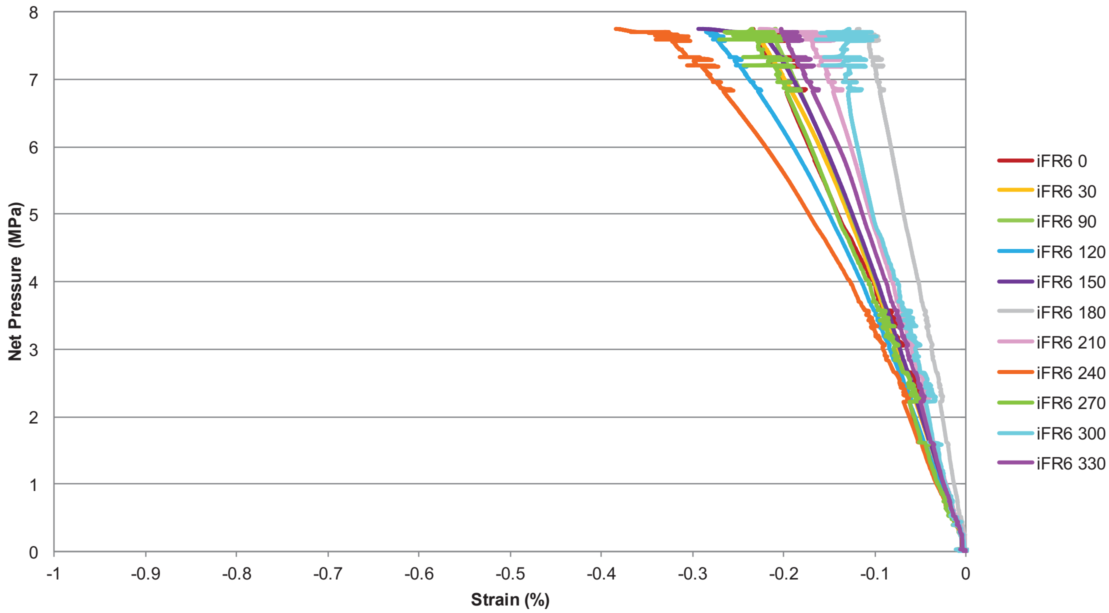


Figure 5.8: Circumferential strains on the flange of T-frame 6 of Specimen A – Baseline.

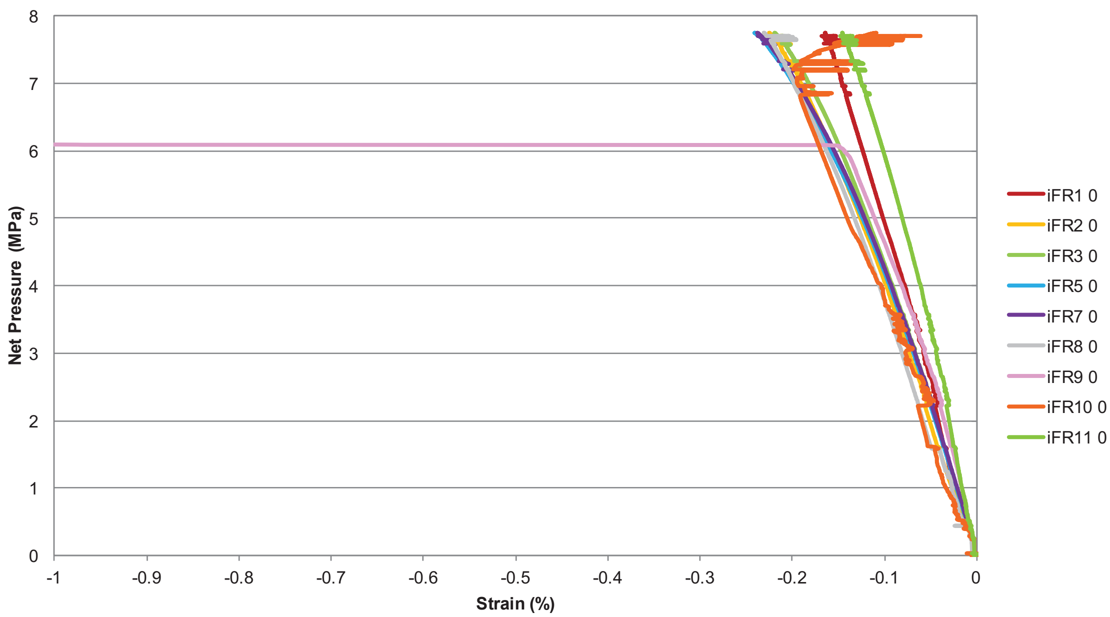


Figure 5.9: Circumferential strains on the flanges of T-frames 1-5 and 7-11 of Specimen A – Baseline.

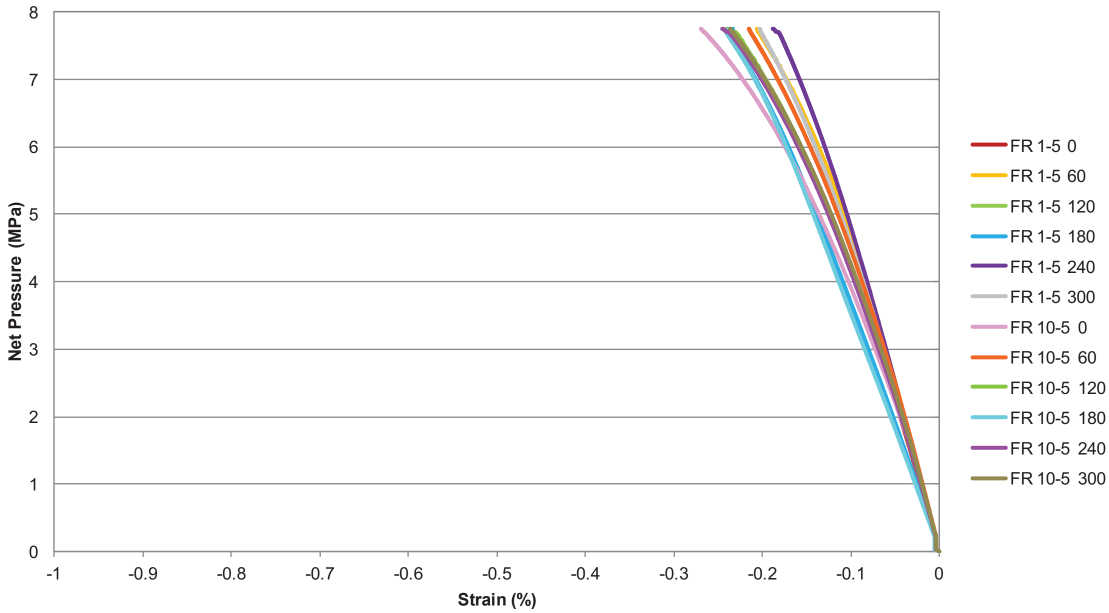


Figure 5.10: Longitudinal strains mid-bay between T-frames1-2 and 10-11 for Specimen A – Baseline.

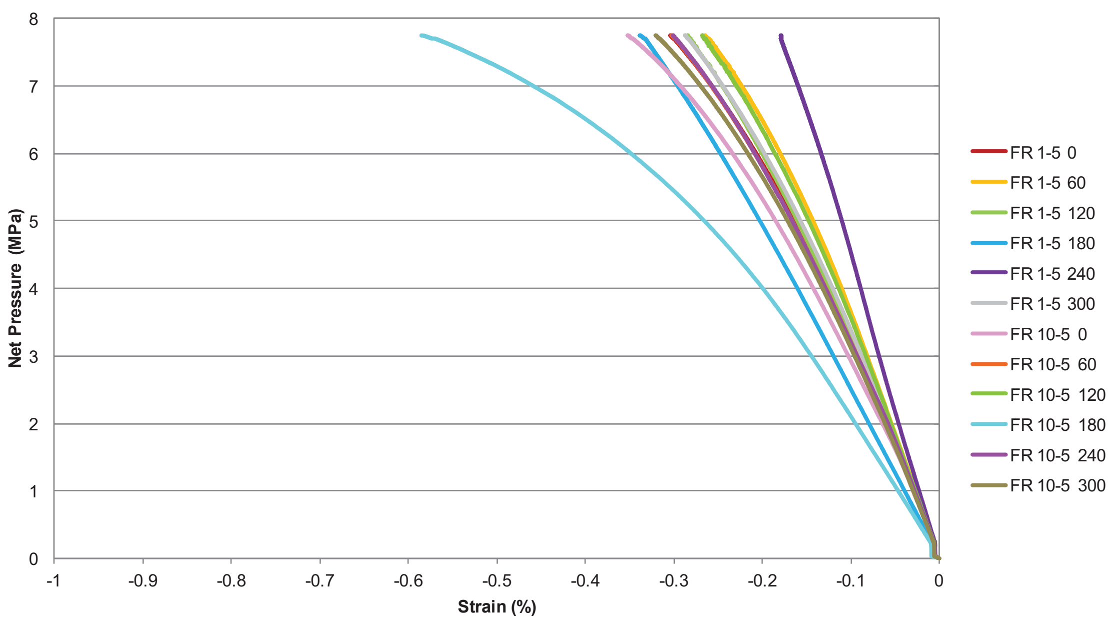


Figure 5.11: Circumferential strains mid-bay between T-frames 1-2 and 10-11 for Specimen A – Baseline.

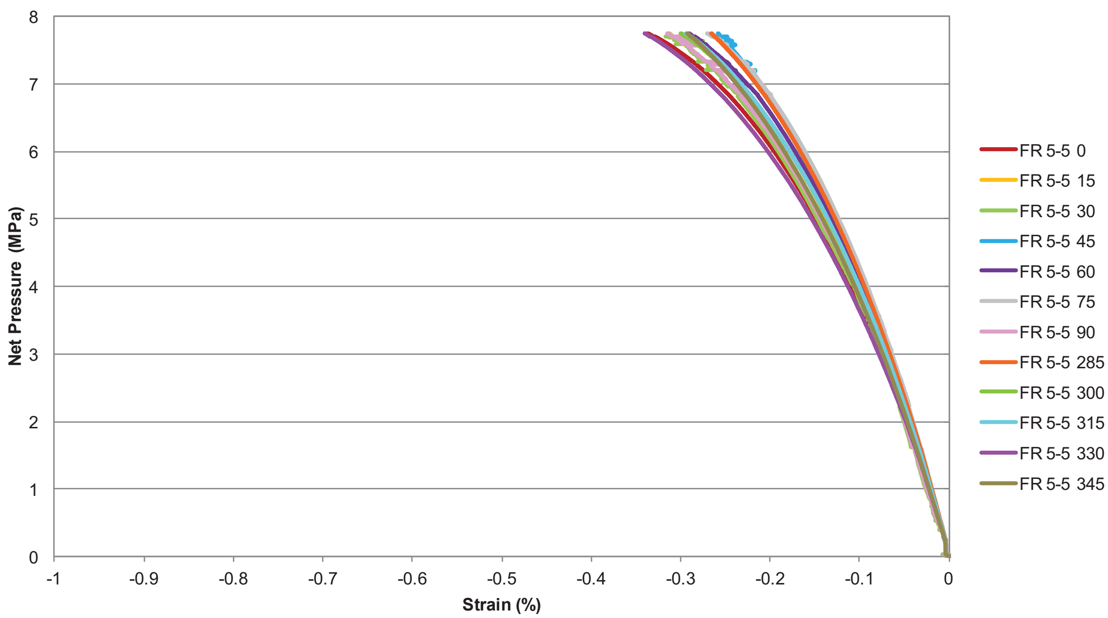


Figure 5.12: Longitudinal strains mid-bay between T-frames 5-6 and 0°±90° for Specimen A – Baseline.

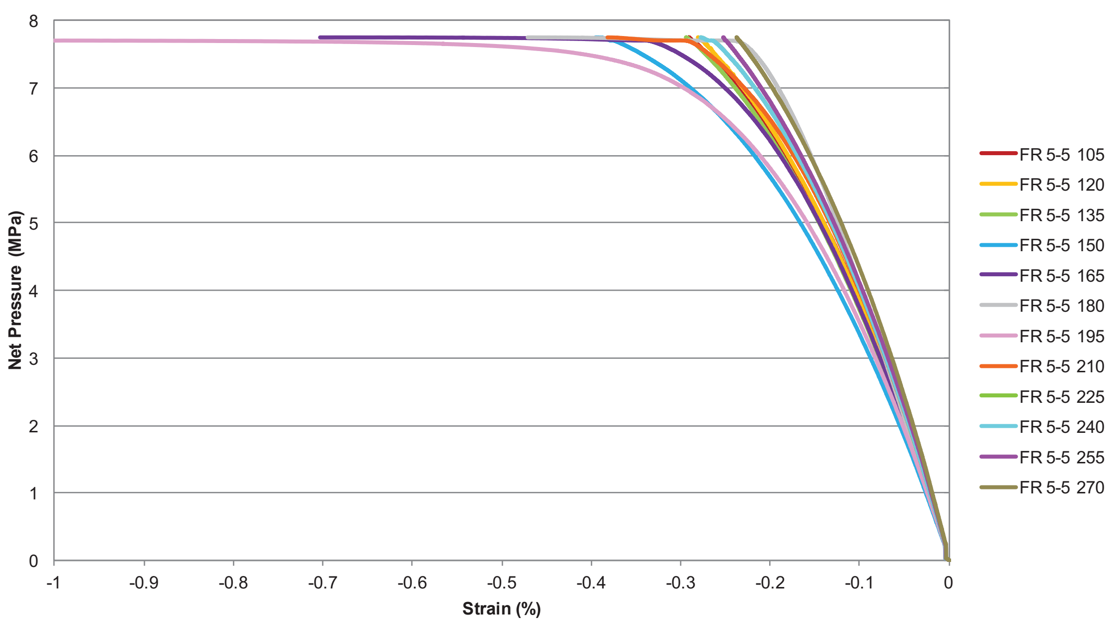


Figure 5.13: Longitudinal strains mid-bay between T-frames 5-6 and 180°±90° for Specimen A – Baseline.

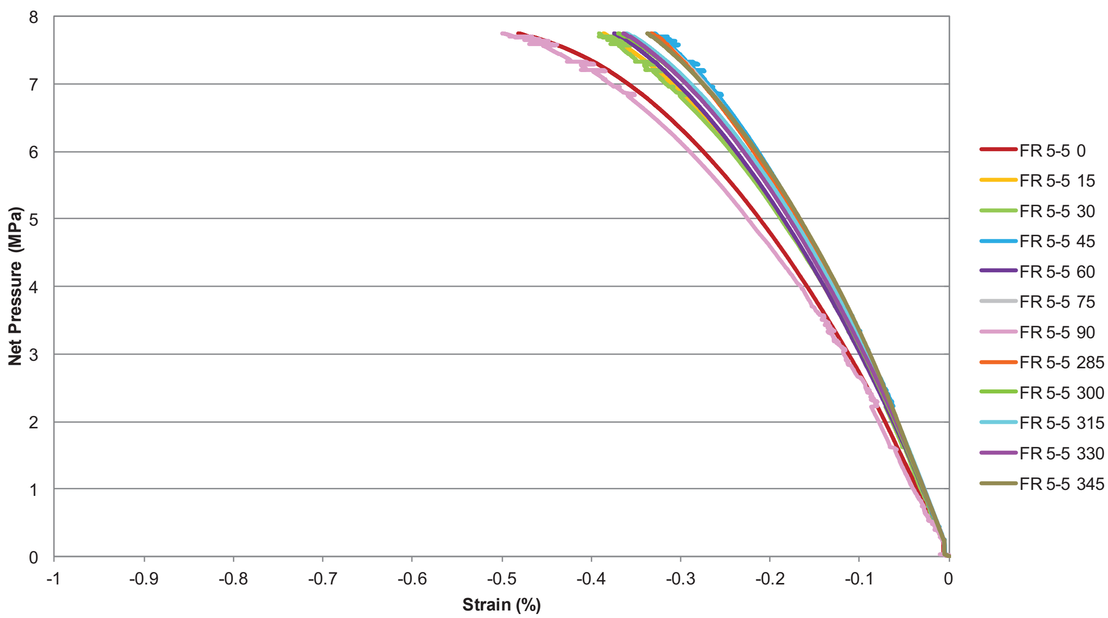


Figure 5.14: Circumferential strains mid-bay between T-frames 5-6 and 0°±90° for Specimen A – Baseline.

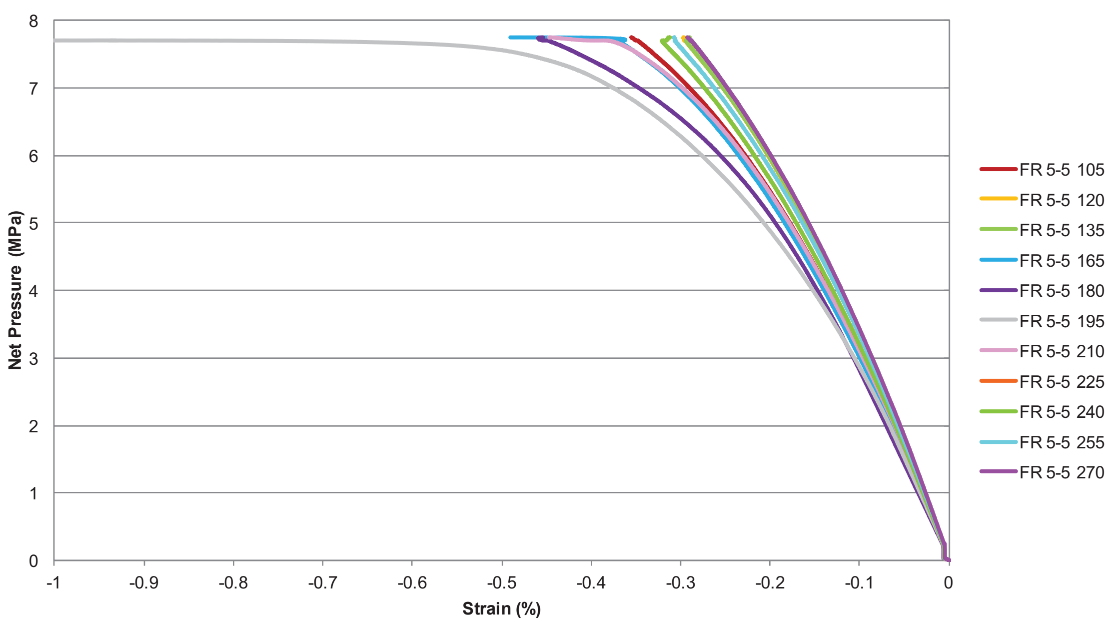


Figure 5.15: Circumferential strains mid-bay between T-frames 5-6 and 180°±90° for Specimen A – Baseline.

5.2.3.2 Specimen B – Damaged

Specimen B sustained a net differential pressure of 7.31 MPa. The specimen experienced interframe collapse with the initial buckle occurring in the region of simulated corrosion. Post-test photos are provided in Figure 5.16.

Based on the strain gauge data, initial shell plate yielding was estimated to have occurred 30 mm from the centre of the corrosion area, mid-bay between T-frames 5 and 6 at approximately 53% of the collapse pressure. The majority of pre-collapse shell plate yielding was in or adjacent to the simulated corrosion area. T-frame yielding did not occur until approximately 92% of the collapse load on T-frame 6 at 330°. The majority of T-frame yielding occurred post-collapse.

The pressure-strain plots for Specimen B are provided in Figures 5.17 to 5.24. It should be noted that failed strain gauges are not included in the figures.

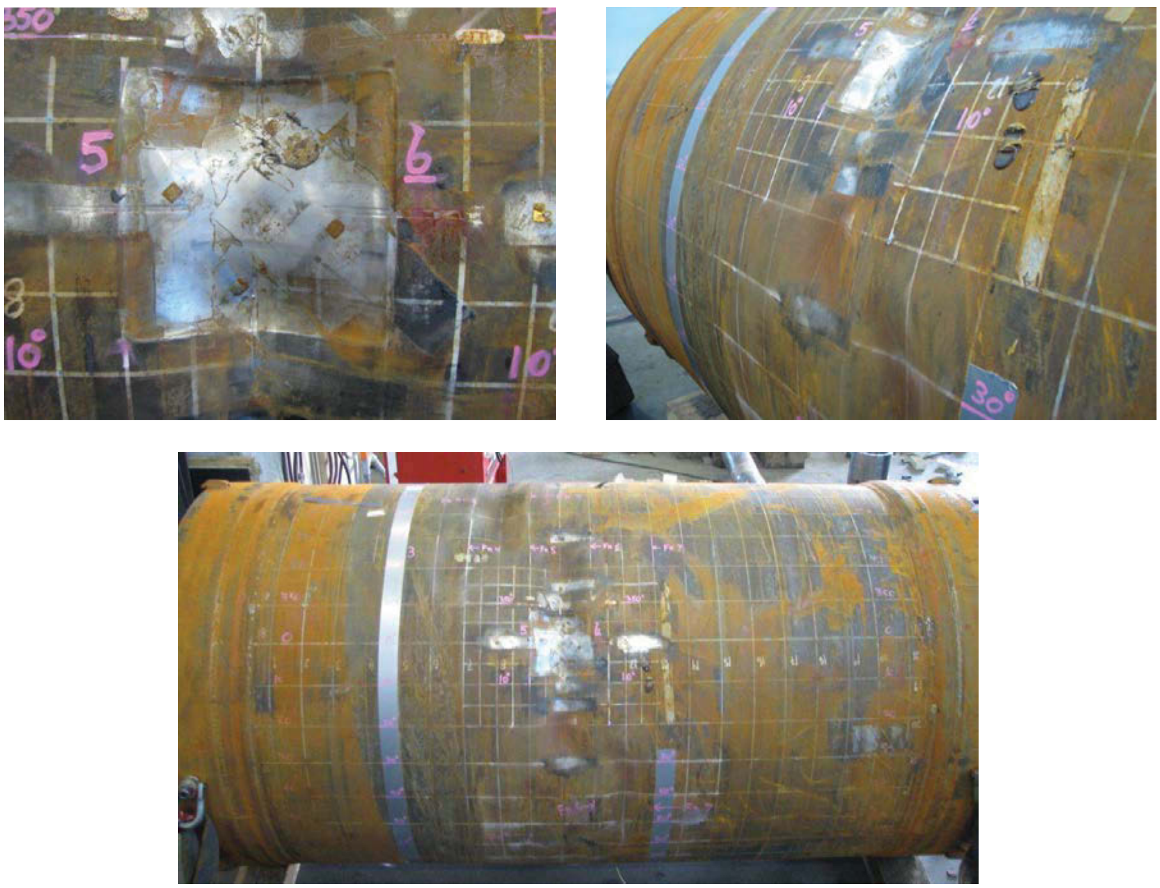


Figure 5.16: Post-collapse photos of cylinder Specimen B – Damaged.

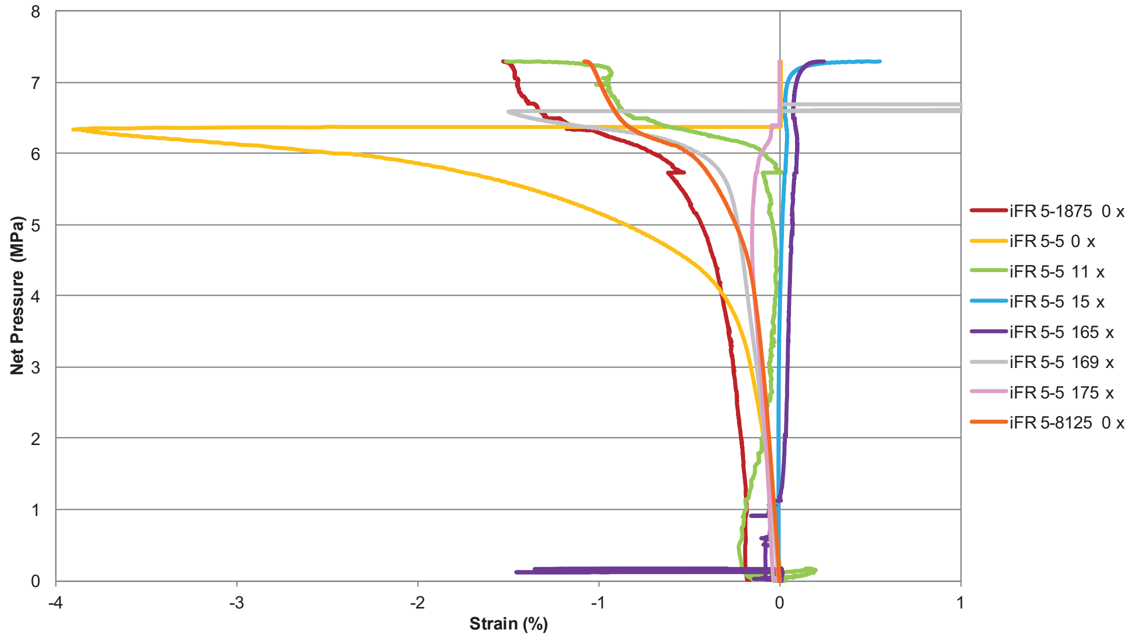


Figure 5.17: Longitudinal internal shell strains between T-frames 5 and 6 for Specimen B – Damaged.

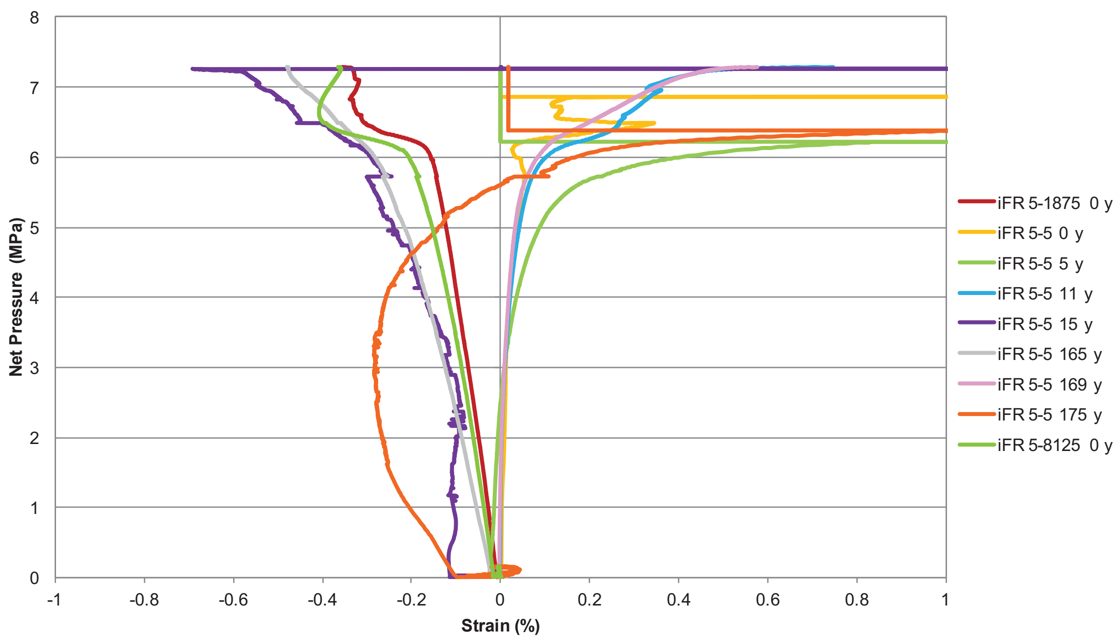


Figure 5.18: Circumferential internal strains between T-frames 5 and 6 for Specimen B – Damaged.

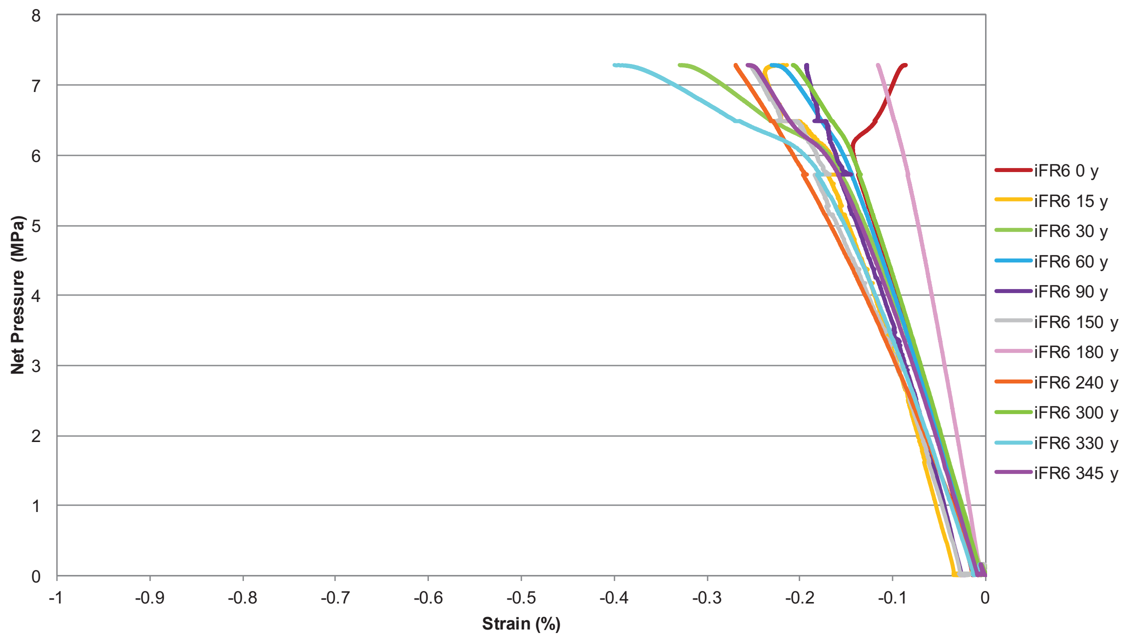


Figure 5.19: Circumferential internal strains around the flange of T-frame 6 for Specimen B – Damaged.

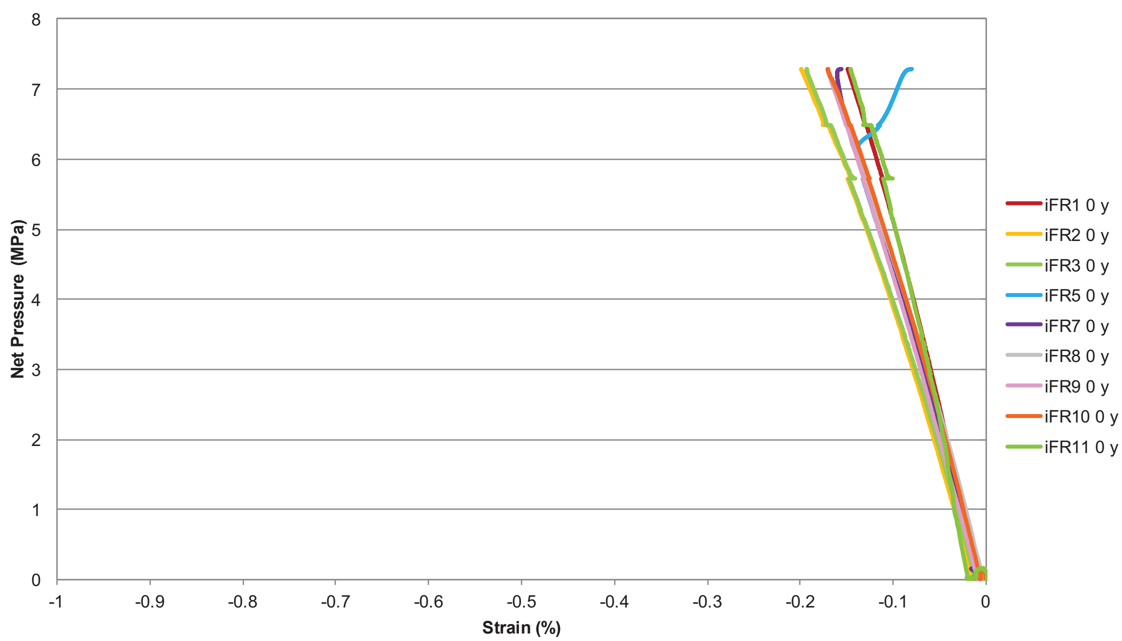


Figure 5.20: Circumferential internal strains on the flange of T-frames 1-5 and 7-11 at 0° for Specimen B – Damaged.

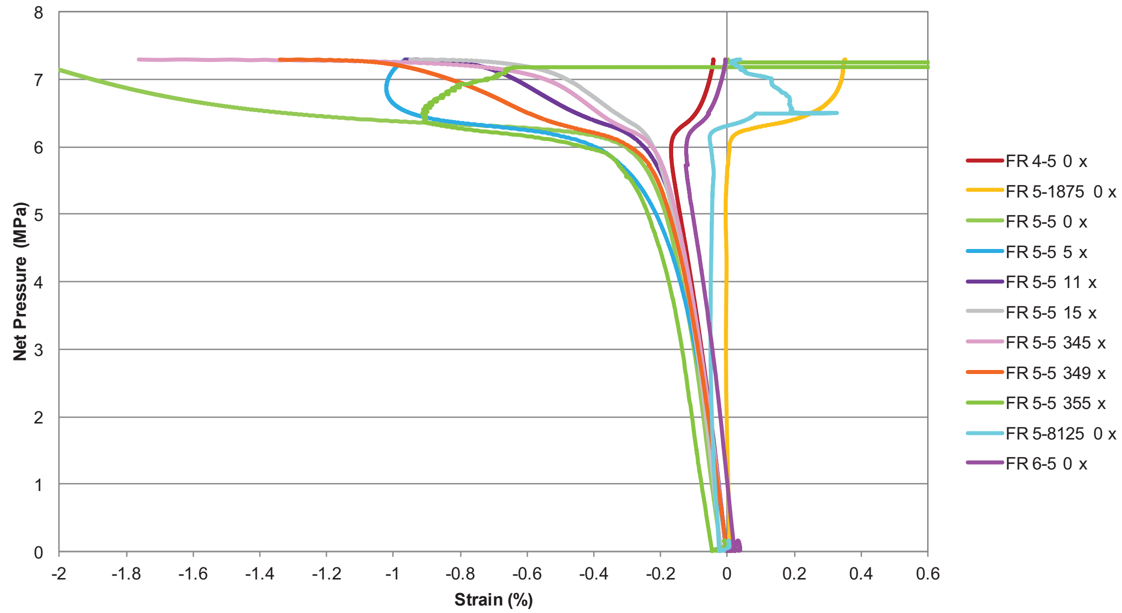


Figure 5.21: Longitudinal external shell strains inside the fine grid area for Specimen B – Damaged.

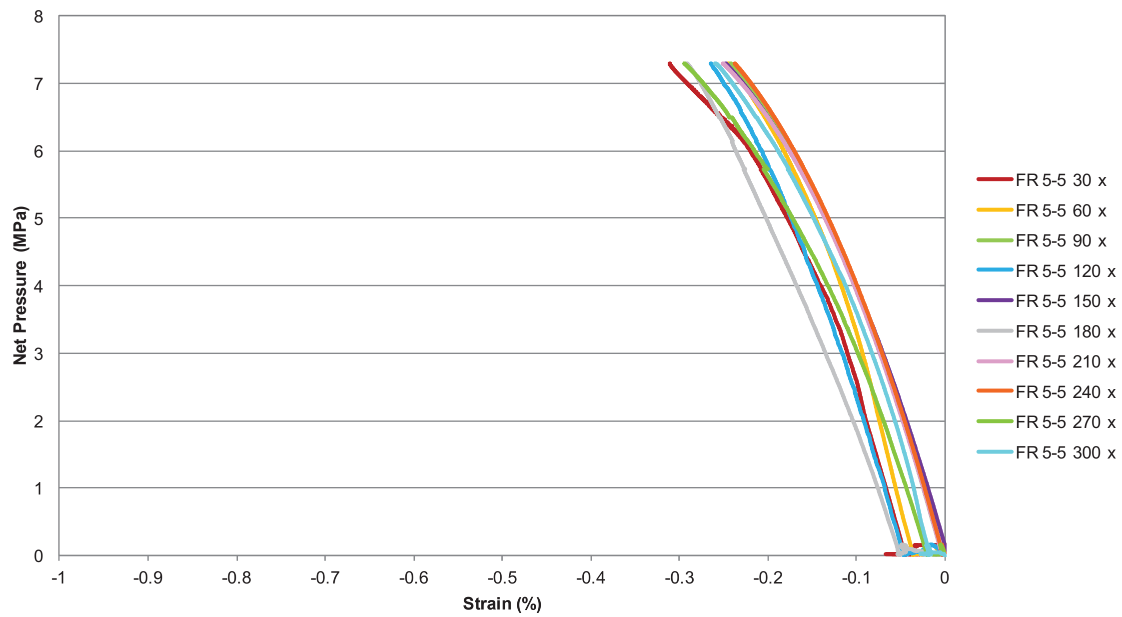


Figure 5.22: Longitudinal external shell strains outside the fine grid area for Specimen B – Damaged.

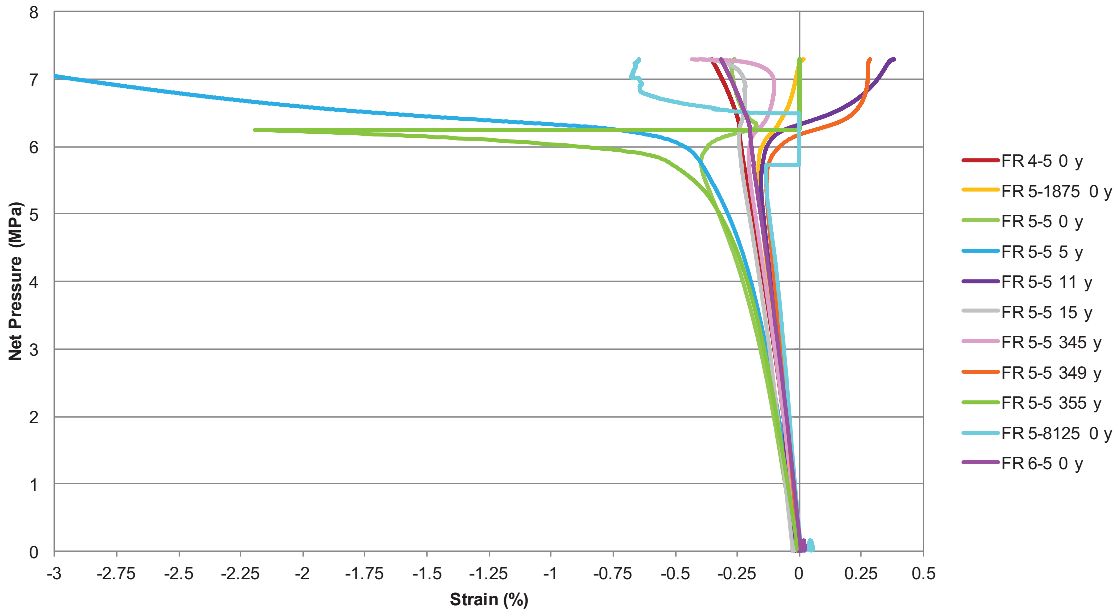


Figure 5.23: Circumferential external shell strains inside the fine grid area for Specimen B – Damaged.

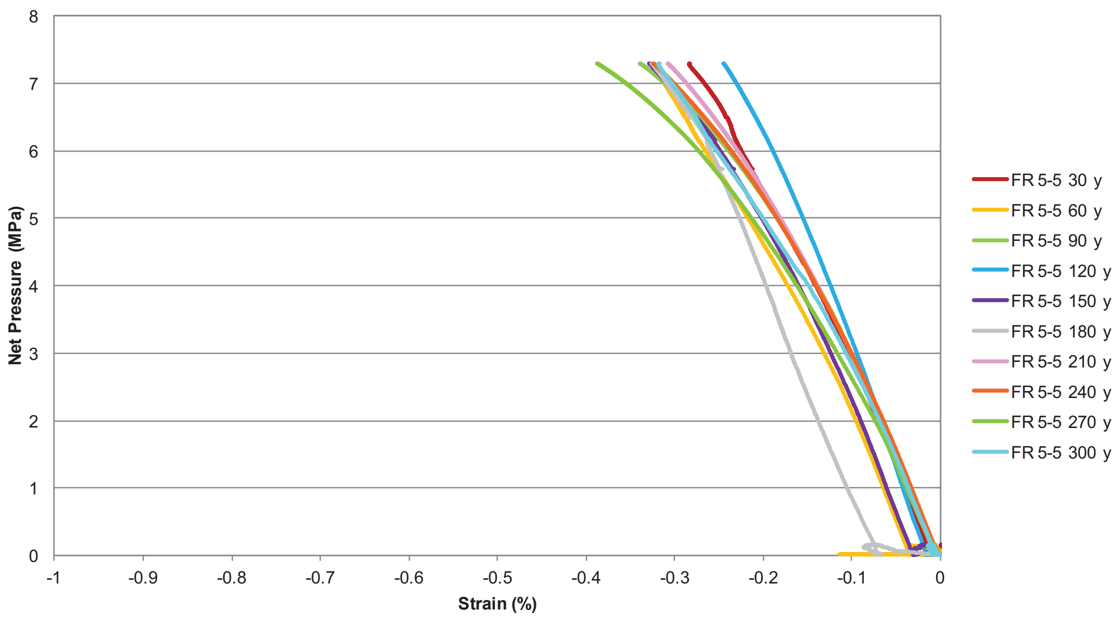


Figure 5.24: Circumferential external shell strains outside the fine grid area for Specimen B – Damaged.

5.2.3.3 Specimen C – Repaired

Specimen C sustained a peak differential pressure of 7.66 MPa. The specimen failed by interframe collapse with the initial buckle occurring in the region of weld repair. Post-test photos are provided in Figure 5.25.

Based on the strain gauge data, initial shell yielding was estimated to have occurred 15° from the centre of the repaired area, mid-bay between T-frames 5 and 6 at approximately 59% of the collapse pressure. The majority of pre-collapse shell yielding was in or adjacent to the repaired area. T-frame yielding did not occur until approximately 94% of the collapse load on T-frame 6 at 15°.

The pressure-strain plots for Specimen C are below in Figures 5.26 to 5.33. It should be noted that failed strain gauges are not included in the figures.

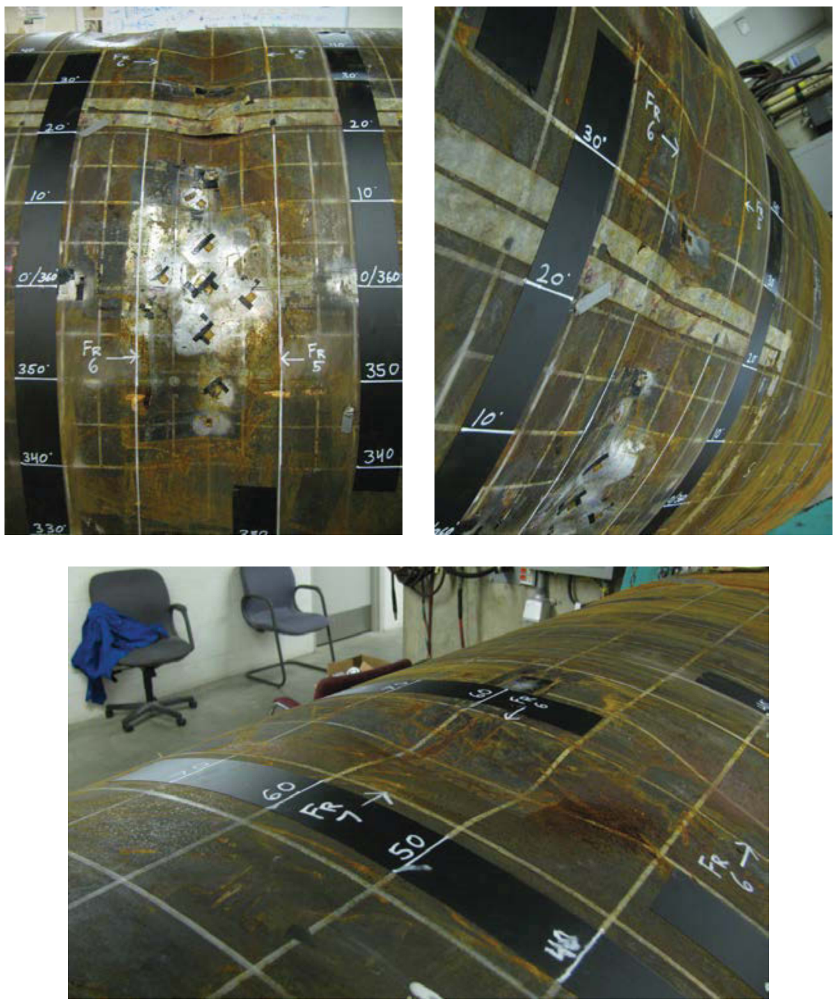


Figure 5.25: Post-collapse photos of cylinder Specimen C – Repaired.

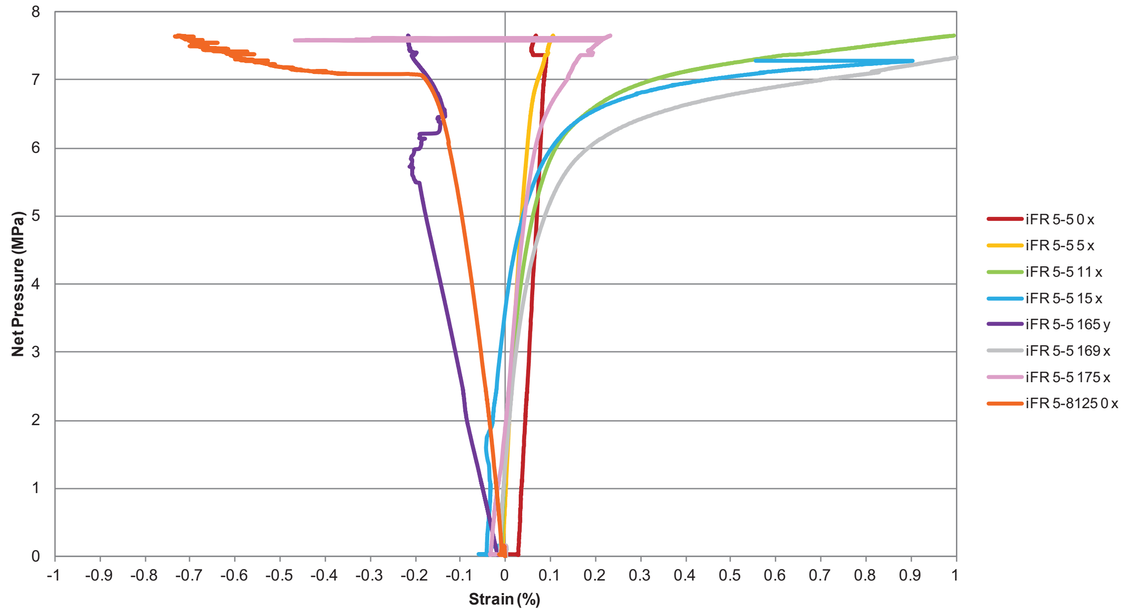


Figure 5.26: Longitudinal internal shell strains between T frames 5 and 6 for Specimen C – Damaged.

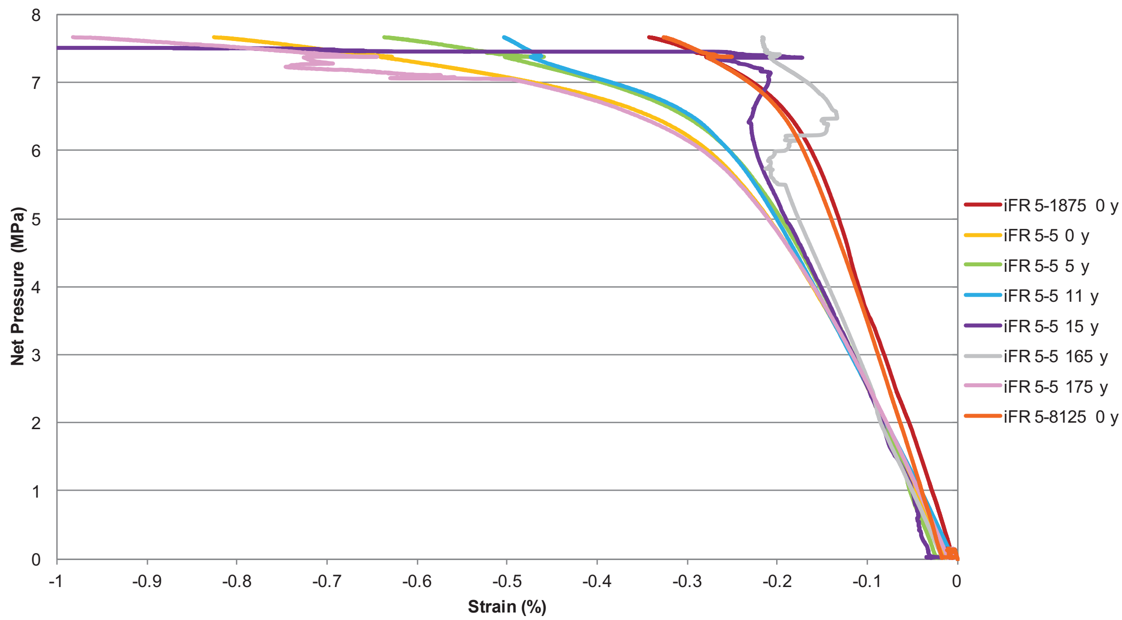


Figure 5.27: Circumferential internal strains between T-frames 5 and 6 for Specimen C – Damaged.

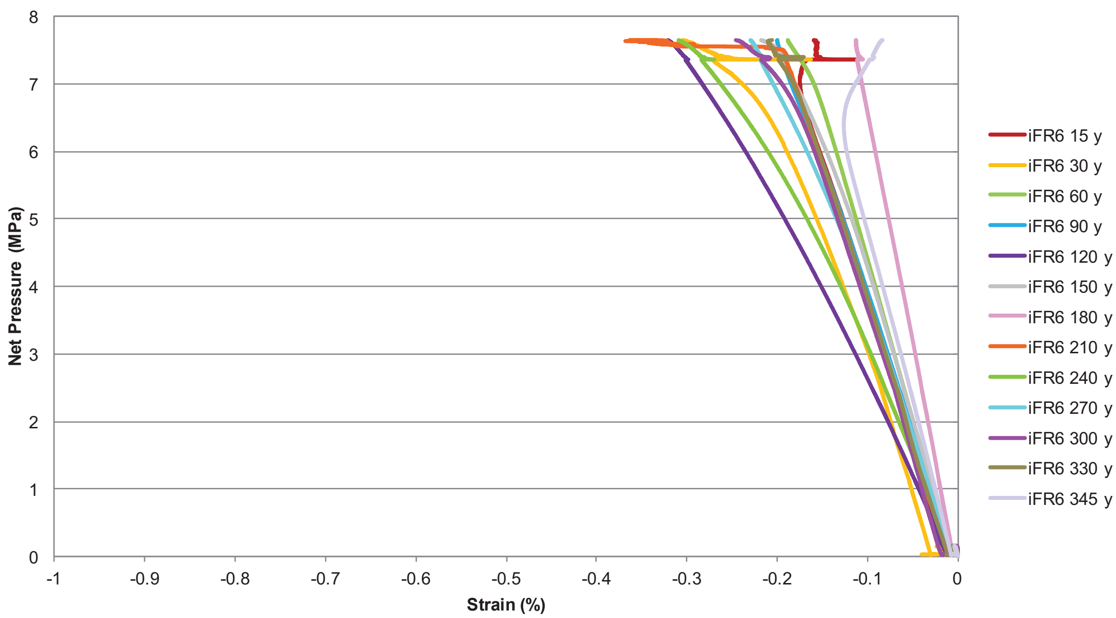


Figure 5.28: Circumferential internal strains around the flange of T-frame 6 for Specimen C – Damaged.

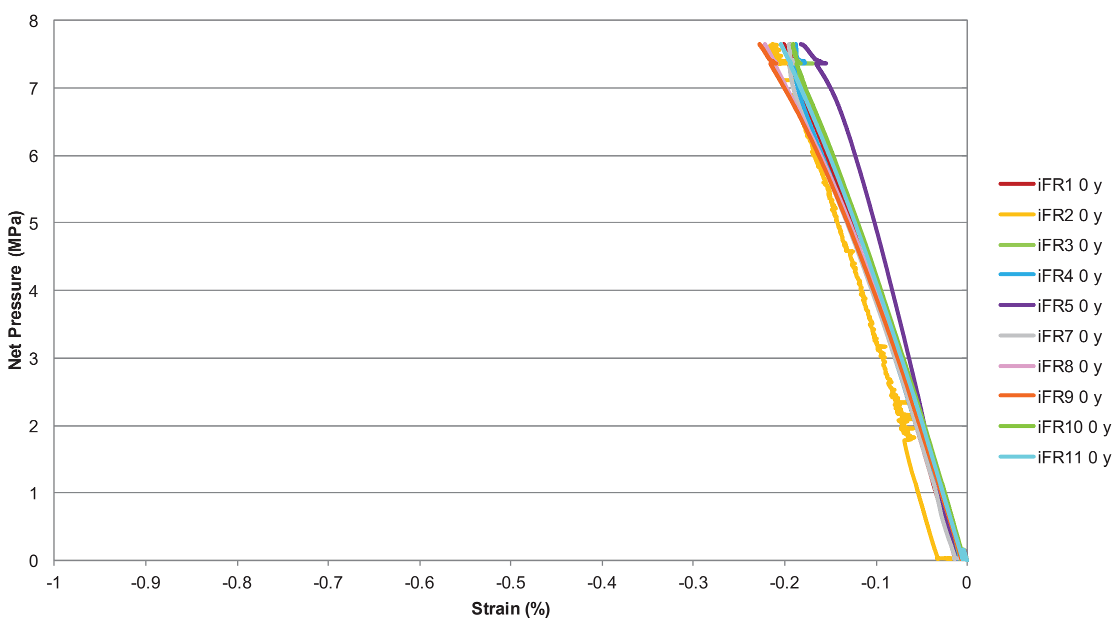


Figure 5.29: Circumferential internal strains on the flange of T-frames 1-5 and 7-11 at 0° for Specimen C – Damaged.

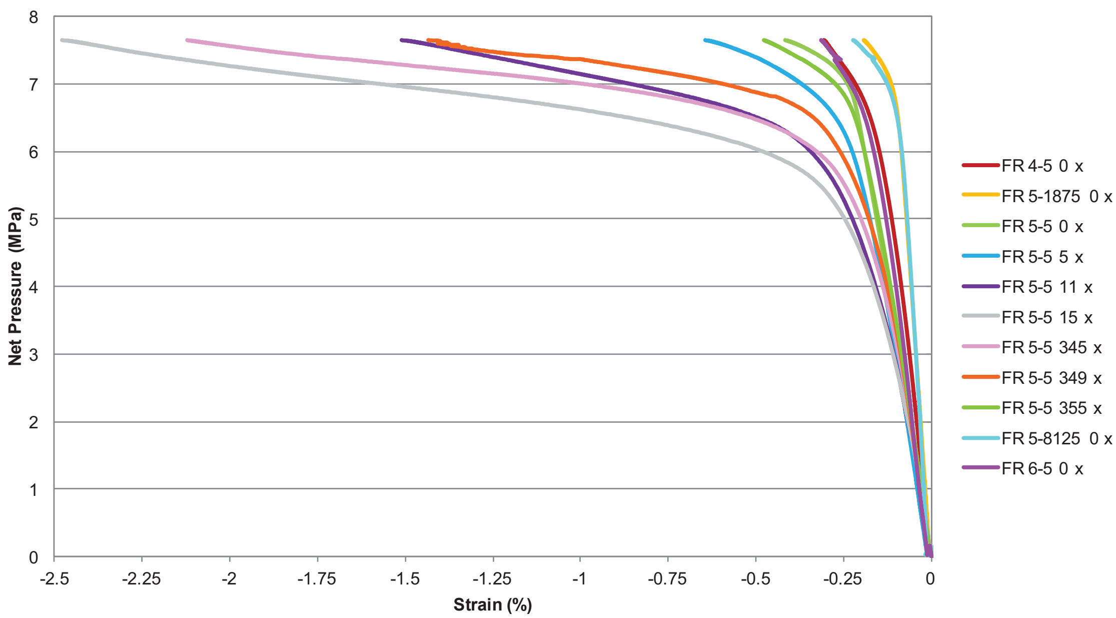


Figure 5.30: Longitudinal external shell strains inside the fine grid area for Specimen C – Damaged.

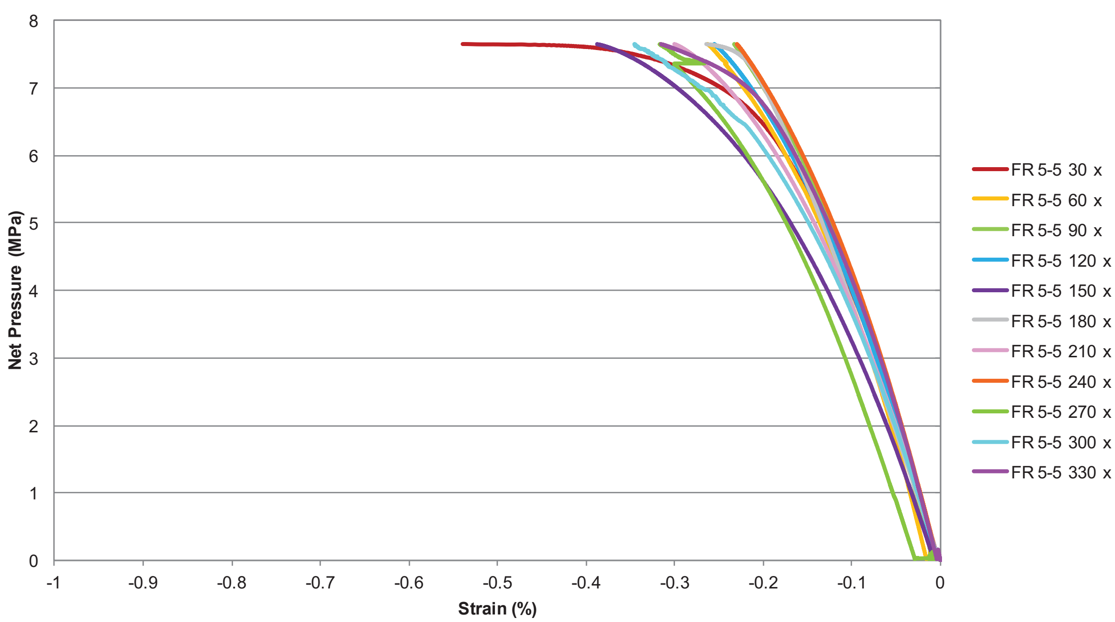


Figure 5.31: Longitudinal external shell strains outside the fine grid area for Specimen C – Damaged.

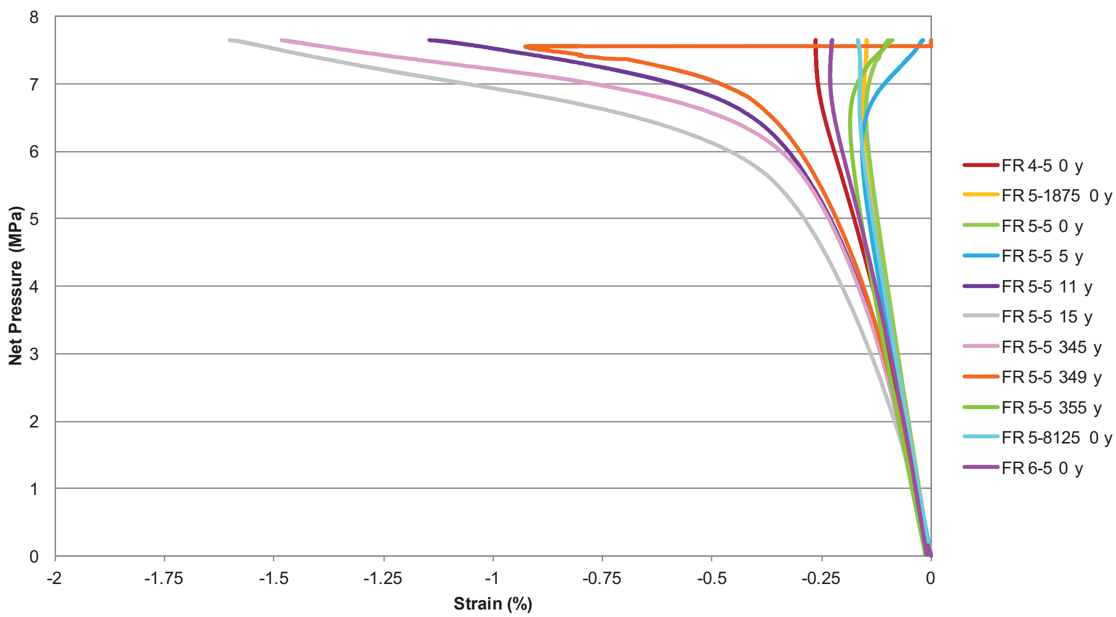


Figure 5.32: Circumferential external shell strains inside the fine grid area for Specimen C – Damaged.

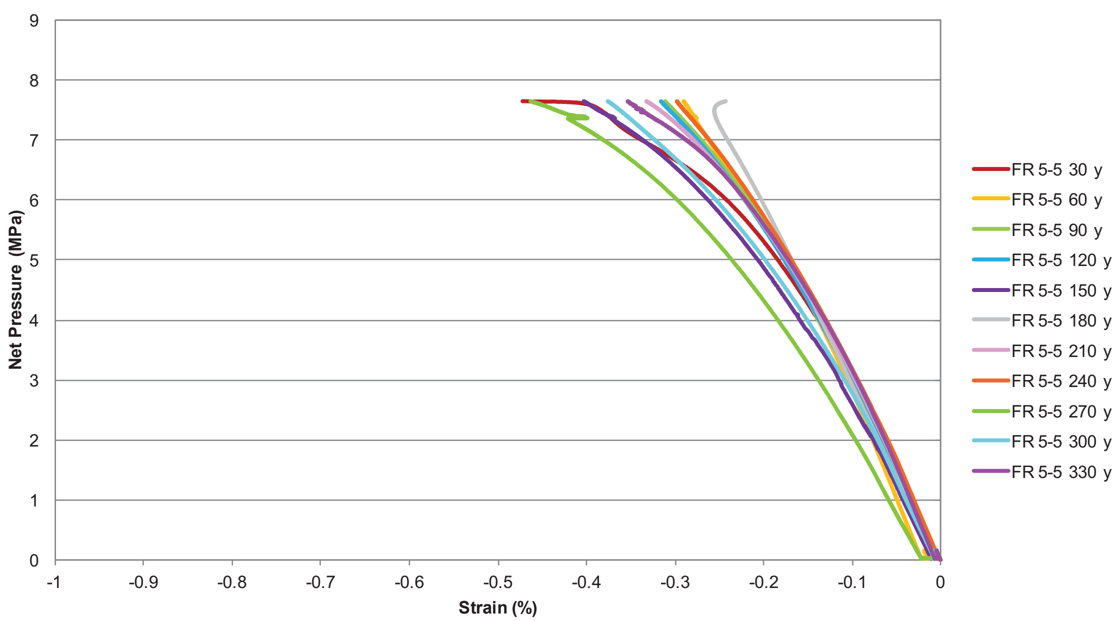


Figure 5.33: Circumferential external shell strains outside the fine grid area for Specimen C – Damaged.

5.2.3.4 Collapse Test Summary

A summary of the collapse pressure, failure mode and post-yield mode shape for each specimen is provided in Table 5.4.

Table 5.4: Summary of collapse test results for each specimen.

Cylinder	First Yielding of the Shell Plate		First Yielding of the T-frame		Collapse Pressure (MPa)	Failure Mode
	Location	P_y (MPa)	Location	P_y (MPa)		
Specimen A	Mid-bay between T-frames 10 and 11	5.31	T-frame 6 at 120°	7.21	7.75	Interframe
Specimen B	50-mm from Frame 5 between T-frames 5 and 6	3.89	T-frame 6 at 330°	6.69	7.31	Interframe
Specimen C	15° from centre of repair are mid-bay between T-frames 5 and 6	4.50	T-frame 6 at 15°	7.22	7.66	Interframe

6 Discussion and Conclusions

6.1 Experimental versus Predicted Collapse Capacity

A direct comparison between the experimental results obtained for Specimen A (baseline specimen without damage) and the two FE analyses described in Section 4 is provided in Table 6.1.

Table 6.1: Summary of collapse test and FE results for Specimen A – Baseline.

	Collapse Pressure (MPa)	Failure Mode	Failure Location
Collapse Test	7.75	Interframe	Mid-bay between T-frames 5 and 6 in the range of 165° to 195°
LS-DYNA Analysis	7.86	Mixed mode	Between T-frames 3 and 5 near seam weld
VAST Analysis	8.02	Overall buckling	Between T-frames 1 and 3 near seam weld

The tabulated results indicate close agreement between the numerical and experimental results with respect to collapse pressure, with the LS-DYNA and VAST analyses overestimating the collapse pressure by only 1.4% and 3.5%, respectively. Both FE analyses also predicted the circumferential location of failure to be in the vicinity of the seam weld, which is consistent with that of the test specimen that collapsed in the 165° to 195° location (with the seam weld being located at 180°). However, with respect to the axial location of failure, the FE analyses predicted that collapse would occur closer to the end caps, whereas the test specimen collapsed mid-bay between T-frames 5 and 6. In addition, the actual specimen failure mode was interframe, whereas the FE analyses predicted either mixed mode or overall buckling.

6.2 Effect of Simulated Metal Loss on Collapse Pressure

A reduction in wall thickness over an isolated area, intended to simulate corrosion damage, resulted in a collapse pressure for Specimen B that was 5.7% lower than that of the undamaged baseline Specimen A. The point of collapse was centred on the area of reduced wall thickness. The simulated corrosion did not change the failure mode as the initially “undamaged” and “damaged” specimens both experienced interframe failure.

6.3 Effect of Weld Repair on Collapse Pressure

Repair of an isolated region of wall loss by weld buttering resulted in a collapse pressure for Specimen C that was only 1.2% lower than that of the undamaged baseline Specimen A. This constitutes a 4.8% increase in collapse pressure compared to the damaged and unrepaired

Specimen B. Effectively, the capacity lost due to metal loss was almost fully recovered by the adopted weld repair procedure. The slight capacity reduction, compared to the undamaged reference specimen, may simply reflect the inherent variability in collapse capacity. However, it may also be attributable, at least in part, to the increased OOC resulting from the shell plate distortion caused by the heat input during weld repair. In general, because collapse is strongly influenced by geometric imperfections, minimizing the conditions that increase OOC should benefit collapse capacity recovery.

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[10] Hosford, W. and Caddell, R. 2007. Metal Forming: Mechanics and Metallurgy. 3rd Edition, Cambridge University Press.

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List of symbols/abbreviations/acronyms/initialisms

List of Symbols

%	Percent
°	Degree
μ	Poisson's ratio
ρ	Density
σ_{yf}	Yield stress of flange
σ_{yp}	Yield stress of plate
a	Mean radius of cylindrical shell
B	Coupon tab length
d	Frame web depth
f	Frame flange depth
E	Young's modulus
h	Shell thickness of cylindrical specimen
h_f	Frame flange thickness
h_w	Frame web thickness of T-frame
kg/m^3	Kilogram per cubic metre
L_B	Overall length of cylindrical specimen
L_f	Frame spacing
MPa	Megapascals
R	Reduced section length
R_{sf}	Safety factor
W_1	Reduced section width
W_2	Coupon tab width

List of Abbreviations/Acronyms/Initialisms

ABS	American Bureau of Shipping
AF	After Fabrication
ASME	American Society of Mechanical Engineers
BPVC	Boiler and Pressure Vessel Code
C-FER	C-FER Technologies
DRDC Atlantic	Defence Research & Development Canada – Atlantic
DEC	Deepwater Experimental Chamber
FE	Finite Element
ISER	International Submarine Engineering Research Ltd.
MPI	Magnetic Particle Inspection
mXRD	Miniature X-Ray Diffractometer
NDE	Non Destructive Examination
OD	Outer Diameter
OOC	Out-of-Circularity
PWGSC	Public Works and Government Services Canada
RFP	Request for Proposal
SC	Simulated Corrosion
SSP	Sea Systems Publications
SubSAS	Submarine Structural Analysis Suite
QA/QC	Quality Assurance / Quality Control
VAST	Vibration and Strength
WB	Weld Buttering

Annex A Final Design Notes

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Design Calculations

1) Preliminary and Final Sizing
2) Stiffener Web to Flange and Shell Welds
3) Solid End Cap
4) End Cap With Hatch
5) Shell Insert at End Cap - Shell Junction
6) Modified End Cap for End Cap Plate #3.

1) Preliminary and Final Sizing

Preliminary:

SSP 74 Design Code used for determining interframe and overall collapse load

Results on "SSP 74 Spreadsheet - Final Configuration 2"

Final:

Elastic-plastic collapse analysis described in SSP 74 used to determine overall buckling collapse load - effect of residual stresses included - Program K79 (Malcolm Smith) does this

Method of Construction

1) Shell is rolled to desired radius and the longitudinal seam is butt welded
2) Stiffener webs are cut in circular segments and welded together (3-4 pieces)
3) Stiffener flanges are rolled to desired radius and welded to stiffener webs.
4) Stiffener web-flange pieces are welded to shell

This means that rolling stresses are considered for shell and flange, but not for web.

Results

Buckling Load (MPa)	Spreadsheet	K79
Interframe	6.798	—
Overall	7.028	7.078[1]

$$\frac{\text{Interframe}}{\text{Overall}} = \frac{6.798}{7.028} = 0.967 > 0.95 \text{ ok}$$

Interframe collapse load within 5% of overall collapse load.

Results Files

1) Spreadsheet.

SSP 74 Spreadsheet – Final Configuration 2.xls

2) K79

Input : Overall Collapse K79.dat

Output : Overall Collapse K79.out

Notes:

(1) K79 analysis performed with slightly different dimensions

$a = 575$ mm
$L_B = 1760$ mm

These make very little difference in SSP 74 Spreadsheet

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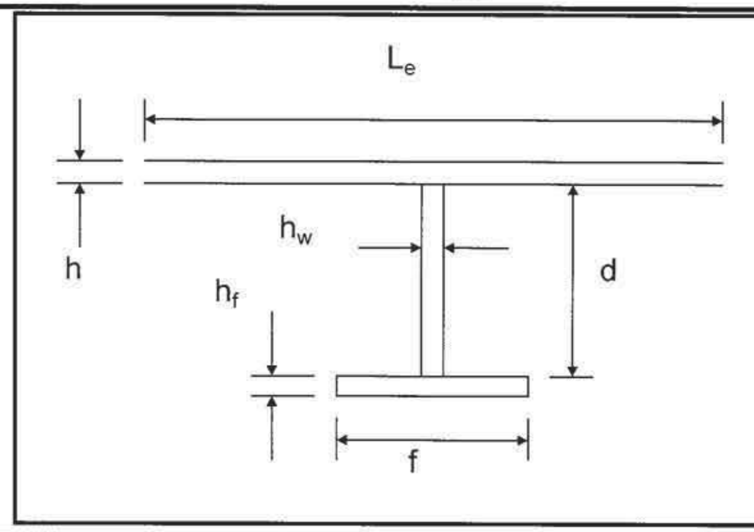
Dartmouth, Nova Scotia
B2Y 3Z7

DEFENCE DÉFENSE

Strength of Ring-Stiffened Cylinders and Unstiffened Dome Ends Under External Pressure



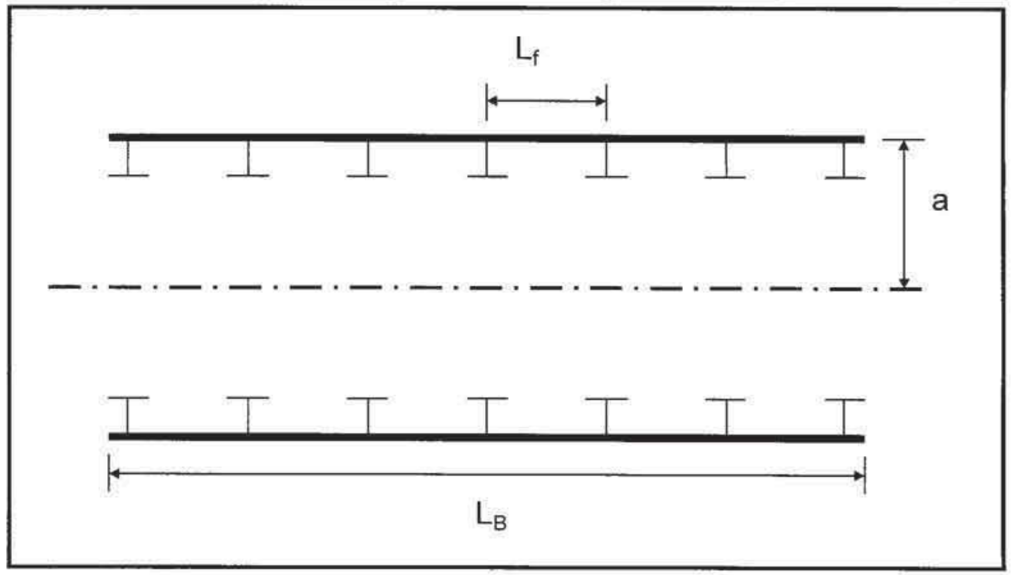
Design Variables

Material Properties (Metric):

E	207000	MPa
σ_{yp}	646.0	MPa
σ_{yf}	646.0	MPa
μ	0.3	
ρ	7850.0	kg/m^3

Geometric Properties (Metric):

h	6.350	mm
h_{dome}	0.000	mm
h_w	6.350	mm
d	33.000	mm
h_f	6.350	mm
f	30.000	mm
a	571.825	mm
L_f	160.000	mm
L_B	1840.000	mm
OOC	0.500	%
R_{sf}	1.000	
Int. Frames	yes	



Relative Proportions:

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DEFENCE DÉFENSE

COLLAPSE MODE	EXTERNAL PRESSURE (MPa)	MODE NUMBER (n)
Shell Yielding		
P_{c3}	7.539	N/A
P_{c5}	8.218	N/A
P_{c6}	9.455	N/A
P_{c7}	6.419	N/A
Frame Yielding		
P_{fy}	12.849	N/A
Interframe Collapse		
P_{m}	12.251	N/A
P_{m1}	12.142	13
Lower Bound P_c	5.437	N/A
Mean P_c	6.798	N/A
Overall Collapse		
P_B	5.848	2
P_N	17.933	3
$P_{y(n)}$	7.028	3
P_P	7.140	3

Frame tripping parameters are satisfied

Interframe/overall 0.967

Notes

Material Properties:

E	207000 MPa
σ_{yp}	646 MPa
σ_{yf}	646 MPa
μ	0.3

Geometric Properties:

Internal Frames

h	6.350 mm
h_{dome}	0.000 mm
h_w	6.350 mm
d	33.000 mm
h_f	6.350 mm
f	30.000 mm
a	571.825 mm
L_f	160.000 mm
L_B	1840 mm
OOC	0.500 %
R_{sf}	1.000

Calculated Properties:

N_f	11
$V_{material}$	0.0570 m^3
Mass	447.3 kg
$V_{displaced}$	1.9112 m^3

```
SECTION
160.0    // b   (plate width)
6.35     // plateThick
33.0     // webHeight
6.35     // webWidth
6.35     // flangeThick
30.0     // flangeWidth
1        // interior stiffeners flag

CYLINDER
575.0  // a ← Actual - 571.825.
1760.0    // overallLength ← Actual - 1840.
160.0    // L  (frame spacing)
3        // mode
2.850     // delta
0.0      // phase

MATERIAL
207000  // E
0.3      // pr
646.0    // yieldShell
646.0    // yieldFrame


OPTIONS
2        // residual stresses
1        // stress correction
1  100.0   // effective width option
1   13.52          // finite length correction
0        // interframe interaction correction


MODEL
HALFSHAPE
1500     // number of finite difference steps
15       // plate fibres
15       // web fibres
15       // flange fibres
```

```
-------------------------------------------
-------            K79              -------
-------    A Program for Overall    -------
-------    Elasto-Plastic Collapse  -------
------- of Ring-Stiffened Cylinders -------
-------------------------------------------
     Input File Name  : kendrick4.dat
     Output File Name : kendrick4.out

Record of data input:

SECTION
160     // b   (plate width)
6.35     // plateThick
33    // webHeight
6.35     // webWidth
6.35     // flangeThick
30       // flangeWidth
1        // interior stiffeners flag

CYLINDER
575  // a
1760     // overallLength
160     // L  (frame spacing)
3        // mode
2.85     // delta
0      // phase

MATERIAL
207000  // E
0.3      // pr
646   // yieldShell
646   // yieldFrame

OPTIONS
2        // residual stresses
1        // stress correction
1  100.0   // effective width option
1   13.52          // finite length correction
0        // interframe interaction correction

MODEL
HALFSHAPE
1500     // number of finite difference steps
15       // plate fibres
15       // web fibres
15       // flange fibres



Ring Section Dimensions
-----------------------
Breadth of plating                          160
Shell thickness                             6.35
Web height                                  33
Web thickness                               6.35
Flange width                                30
Flange thickness                            6.35
Internally stiffened
Frame area                                  400.05
Plate area                                  1016
Ratio of frame area to total                0.282511

Material Properties
```

4	16.25	0
5	18.45	0
6	20.65	0
7	22.85	0
8	25.05	0
9	27.25	0
10	29.45	0
11	31.65	0
12	33.85	0
13	36.05	0
14	38.25	0
Shell plating		
0	39.56	230.9
1	39.98	105.6
2	40.41	-19.63
3	40.83	-144.9
4	41.25	-270.2
5	41.68	-304.8
6	42.1	-152.4
7	42.52	0.0001926
8	42.95	152.4
9	43.37	304.8
10	43.79	270.2
11	44.22	144.9
12	44.64	19.63
13	45.06	-105.6
14	45.49	-230.9

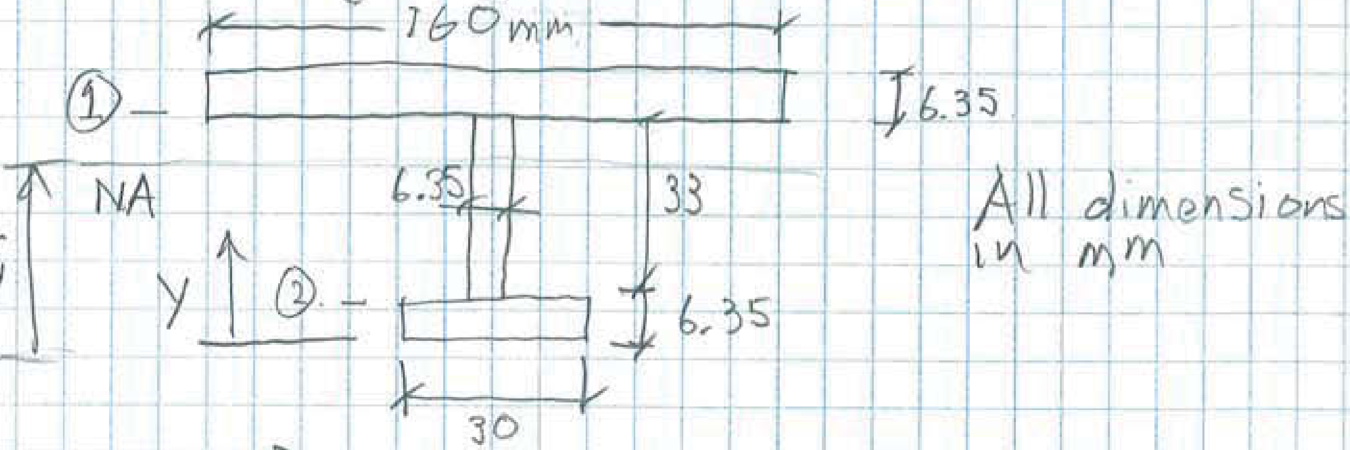
Elasto-plastic calculation

Collapse pressure	7.078
Maximum frame deflection	5.233
Last pressure step size	3.526e-005

Fibre Stresses in Cross-Section

Frame flange		
0	0.2117	-646
1	0.635	-646
2	1.058	-646
3	1.482	-646
4	1.905	-646
5	2.328	-646
6	2.752	-646
7	3.175	-646
8	3.598	-646
9	4.022	-646
10	4.445	-646
11	4.868	-646
12	5.292	-646
13	5.715	-646
14	6.138	-646
Frame web		
0	7.45	-646
1	9.65	-646
2	11.85	-646
3	14.05	-646
4	16.25	-646
5	18.45	-646
6	20.65	-646
7	22.85	-646
8	25.05	-646

2) Stiffener Web to Flange and Shell Welds.



Centroid : $\bar{y} = \dfrac{\Sigma A \bar{y}}{\Sigma A}$

$$\bar{y} = \frac{\overset{(604.84)}{30 \times 6.35 \times 6.35/2} + \overset{(4788.22)}{33 \times 6.35 \times (33/2 + 6.35)} + \overset{(43205.4)}{160 \times 6.35 \times (6.35 + 33 + 6.35/2)}}{\underset{(1416.05)}{30 \times 6.35 + 33 \times 6.35 + 160 \times 6.35}}$$

$\bar{y} = 34.32$ mm

Moment of Inertia

$I = \Sigma I_o + Ad^2$

$$\Sigma I_o = \overset{(640.12)}{\frac{30 \times 6.35^3}{12}} + \overset{(19016.67)}{\frac{6.35 \times 33^3}{12}} + \overset{(2709.84)}{\frac{127 \times 6.35^3}{12}} = 22366.6 \text{ mm}^4$$

$$\Sigma Ad^2 = \overset{(184787.10)}{30 \times 6.35 \times (34.32 - 6.35/2)^2} + \overset{(27560.59)}{33 \times 6.35 \times (34.32 - 22.85)^2}$$
$$+ \overset{(68399.18)}{160 \times 6.35 \times (34.32 - 42.525)^2} = 280746.87 \text{ mm}^4$$

$I = 22366.6 + 280746.87 = 303113.47 \text{ mm}^4$

Shear Capacity : CAN3-S16.1-M78 13.4.1

Unstiffened Web : $k_v = 5.34$

$$\frac{h}{w} = \frac{33}{6.35} = 5.197 \qquad 439\sqrt{\frac{k_v}{F_y}} = 439\sqrt{\frac{5.34}{646}} = 39.91$$

(S16.1 13.4.1) $F_s = 0.66 F_y = 0.66 \times 646 = 426.36$ MPa

$V_r = \phi A_w F_s$

$= 0.9 \times 6.35 \times 33 \times 426.36 = 80409.36$ N/mm

Web to Shell Junction

$q = \frac{VQ}{I}$

$Q = (\Sigma A\bar{y})_1$

$= (160 \times 6.35) \times (42.525 - 34.32) = 8336.28 \text{ mm}^3$

$q = \frac{80409.36 \times 8336.28}{303113.47} = 2211.43$ N/mm

S16.1 13.13.2.1

1) Weld metal strength $= 0.67 \phi A_w X_u$ — assume matched electrode

$X_u = 711$ MPa from mill cert

$= 0.67 \times 0.9 \times (1 \times 0.7071) \times 711 \quad 303.16$ N/mm

2) Base metal strength $= 0.67 \phi A_m F_y$

$= 0.67 \times 0.9 \times 1 \times 646 = 389.54$ N/mm

Weld thickness required (2 legs) $= \frac{q}{2 \times 1} = \frac{2211.43}{303.16 \times 2} = 3.64$ mm

Use 4 mm weld

Web to Flange Junction

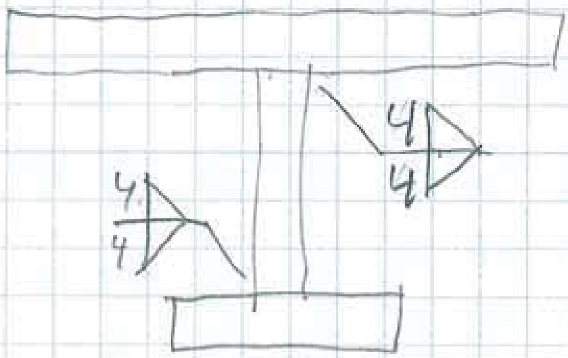
$$Q = (\Sigma A\bar{y})_{②} = 30 \times 6.35 \times (34.32 - 6.35/2)$$
$$= 5933.12 \ mm^3$$

$$q = \frac{80409.36 \times 5933.12}{303113.47} = 1573.93 \ N/mm$$

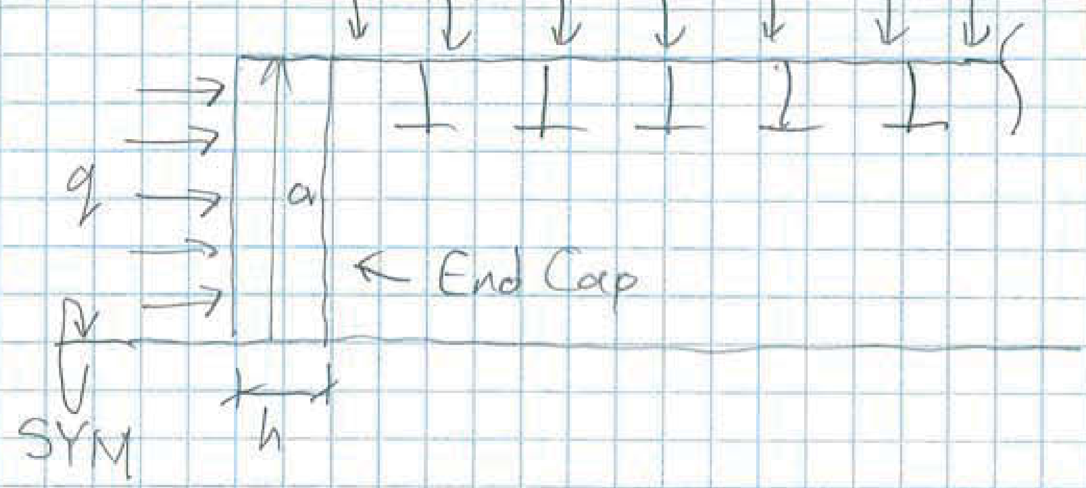
Weld thickness required (2 legs) $= \dfrac{q}{2 \times ①} = \dfrac{1573.93}{2 \times 303.16} = 2.59 \ mm$

3.89

Use 4 mm welds



3) Solid End Cap to Flange and Shell Welds



End Cap Design

1) Simple
2) Removable
3) Stiff - meant to represent bulkhead

C-FER suggested 6" (152.4 mm) 350W plate. Check plate for maximum bending stress.

Model plate as pinned at cap-shell junction. Timoshenko (1959).

$$\sigma_{max} = \frac{3(3+\nu)qa^2}{8h^2}$$

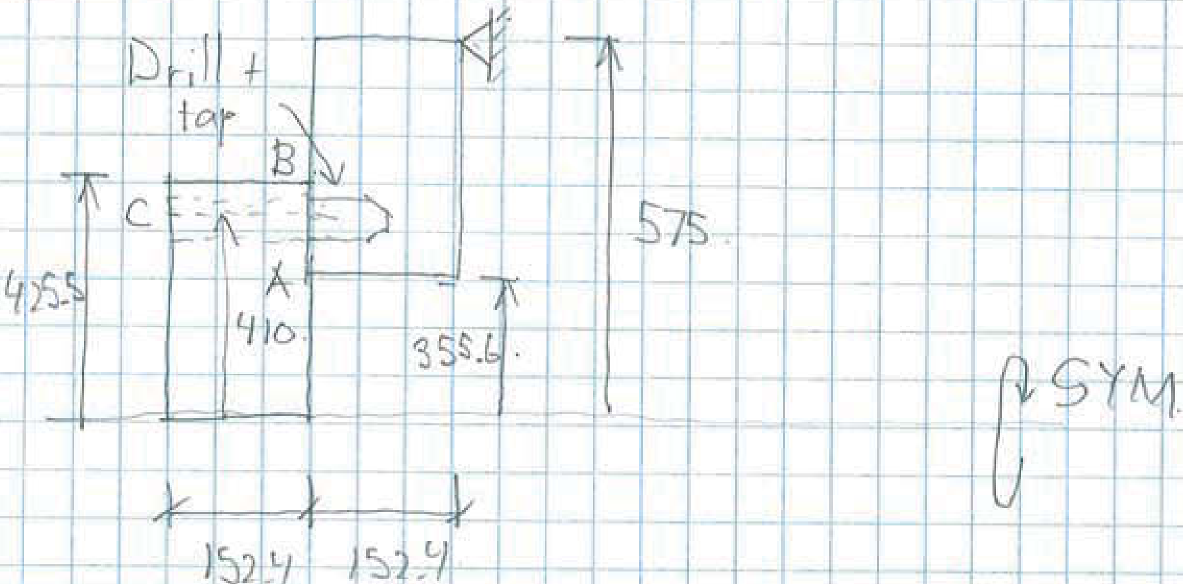
$\nu = 0.3$
$q = 6.762$ MPa
$a = 575$ mm
$h = 152.4$ mm

$$= \frac{3(3+0.3)6.762 \times 575^2}{8 \times 152.4^2} = 119.12 \text{ MPa} < 300$$

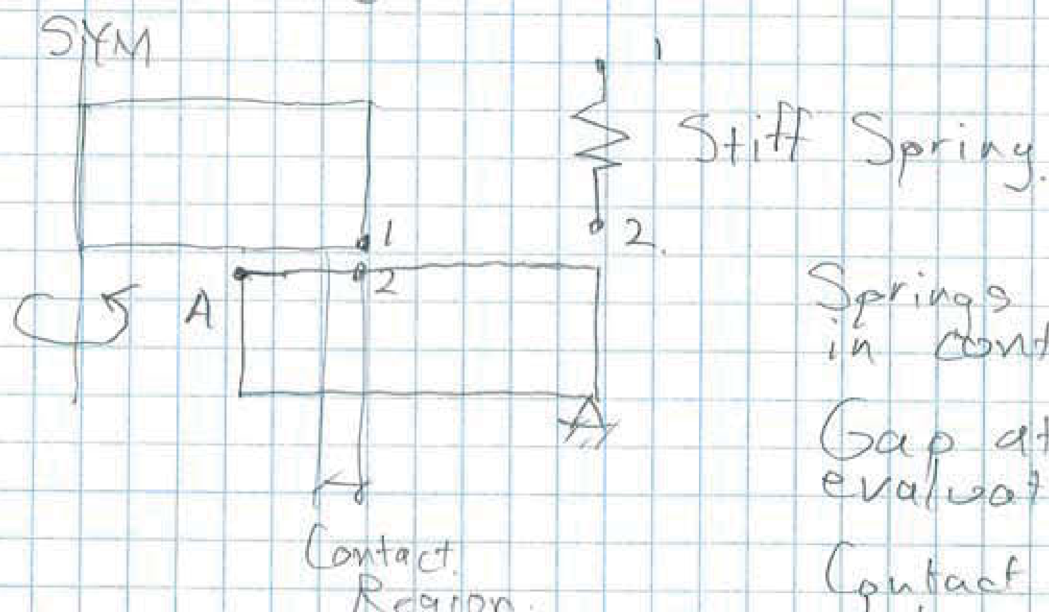
-ok

4) End Cap With Hatch

C-FER suggested the following configuration



Potential problem is that bolt at C may experience prying from bearing at A or B. Use FEA model to compute maximum gap

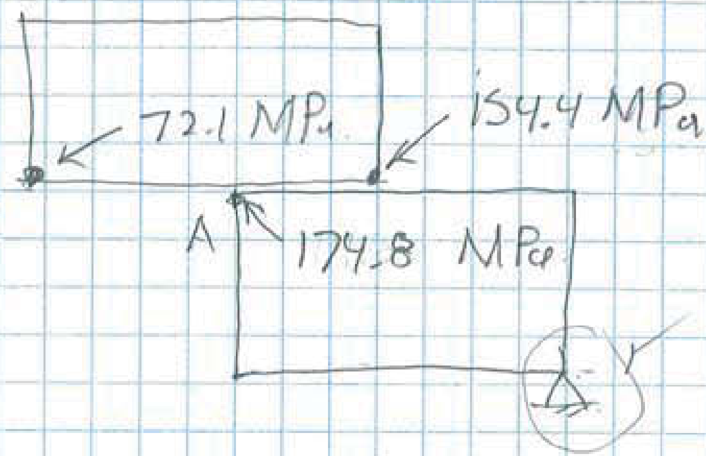


Springs are placed in contact region.

Gap at A is evaluated.

Contact region determined iteratively with springs.

Maximum Stresses



610 - Localized due to boundary condition - ignore

Check gap at A

Gap = 4.542×10^{-5} m

Strain due to gap = $\dfrac{\Delta}{L_{bolt}} \approx \dfrac{4.542 \times 10^{-5}}{0.1524}$

$= 2.980 \times 10^{-4}$

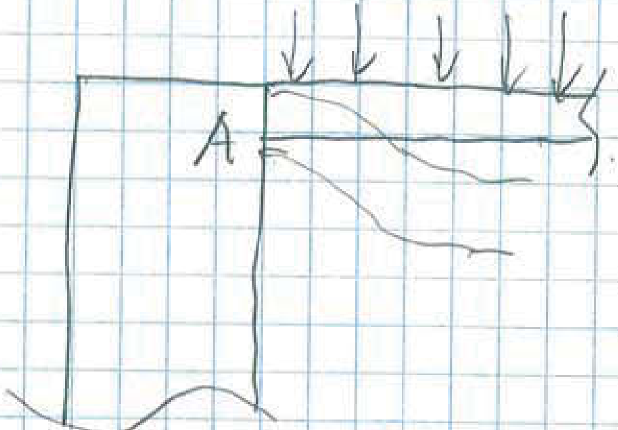
Yield strain = $\dfrac{830}{200{,}000} = 4.15 \times 10^{-3}$ (A490 bolts).

$F_u = 830$ MPa

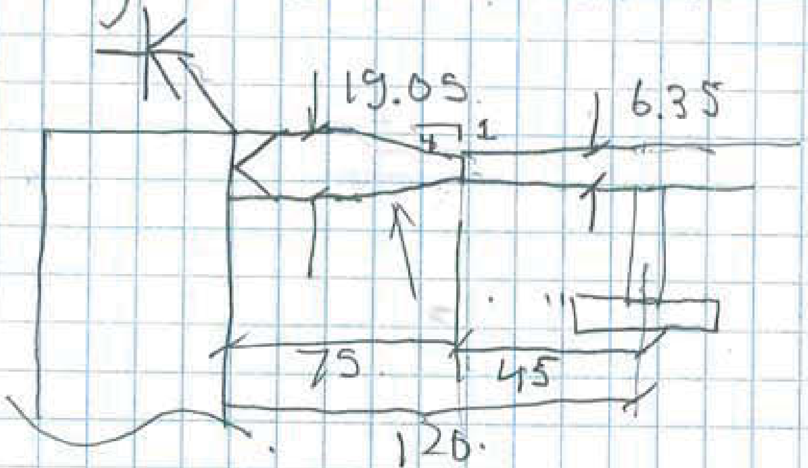
Strain is relatively small ∴ bolts are good

Data Files in "End Cap With Hatch - Gap Check" Folder - binary file "d3plot" can be read with LS-Prepost or Hypermesh

5) Shell Insert at End Cap - Shell Junction.

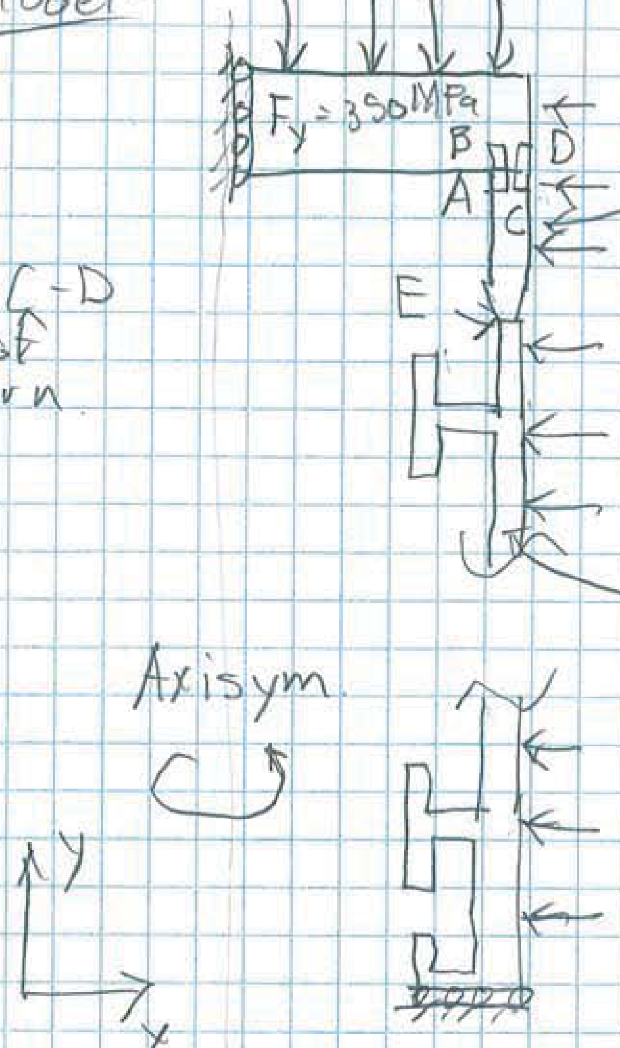


Local bending @ Point A causes large bending stresses - must reduce them



FEA analysis done with LS-DYNA
Model in
End Cap - Shell Junction - Stress Check Final
/LSDYNA/axisym4.dyn

FE model:



$F_y = 100$ ksi (690 MPa)

1.0 MPa pressure

– multiply stresses by 6.8 to get "failure" Stresses

$F_y = 646$ MPa.

A-B-C-D area of Concern

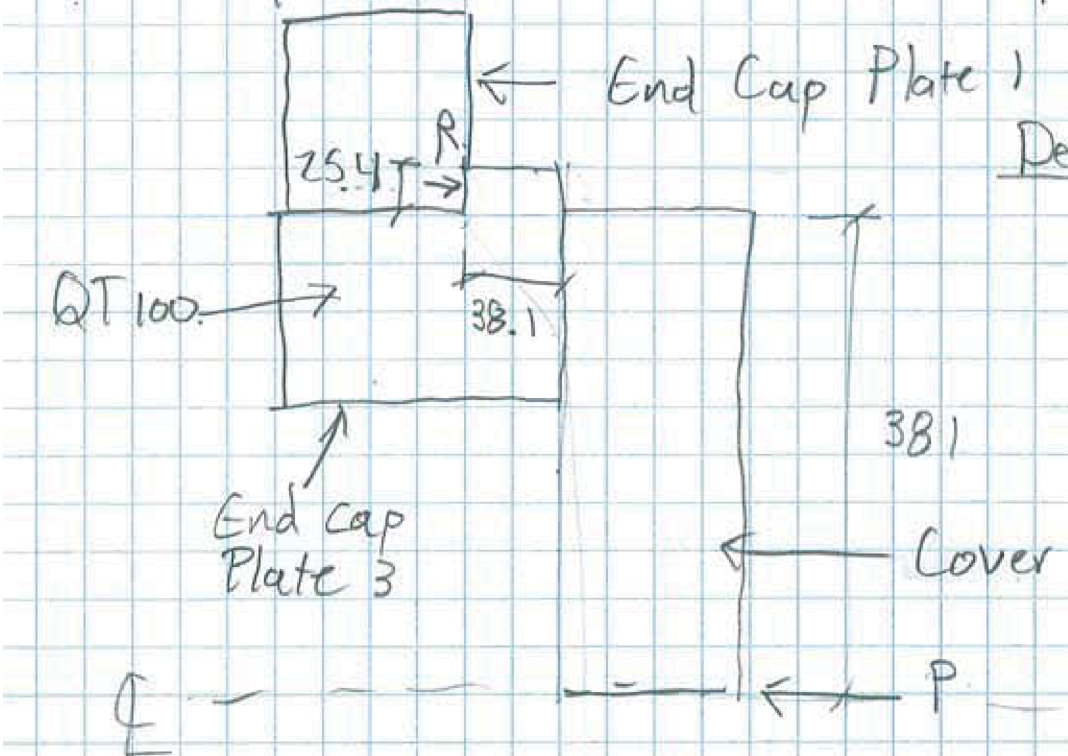
Model geometry, loads, boundary conditions checked 12/15/10

Vertical loading (σ_y) checked 12/15/10.

Results

Location	Mises Stress (MPa)	Yield Stress
A	392.2	690.
B	252.6	350.
C	126.4.	690
D	121.4.	350.
E	498.3	646.

6) End Cap Plate #3 - Shear Lip Check



Design Pressure:

$p = 6.8$ MPa
$= 6.8 \times 10^6$ N/m^2

$P = \pi r^2 p = \pi \times 0.381^2 \times 6.8 \times 10^6 = 3.101 \times 10^6$ N

$A_{shear} = 2\pi r_{avg} h = 2 \times \pi \times (0.381) \times 0.0381$

$= 0.0912$ m^2

S16-1: Shear

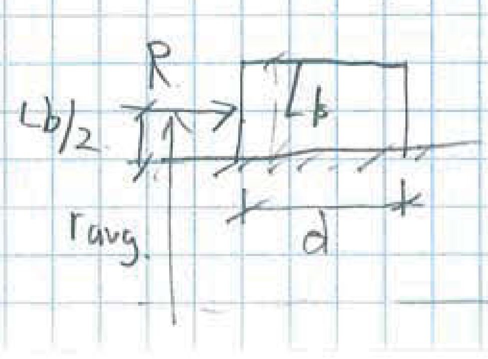
$V_f = \phi A_w F_s$

$F_s = 0.66 \times F_y = 0.66 \times 689.5 = 455.1$ MPa

$V_f = 0.9 \times 0.0912 \times 455.1 \times 10^6 = 37.35 \times 10^6$ N

$> 3.101 \times 10^6$ N ok.

S16.1: Bending



$R = \dfrac{P}{A} L_b$

$A = 2\pi r_{avg} L_b$

$A = 2\pi \times \left(0.381 + \frac{0.0254}{2}\right) \times 0.0254 = 0.06283\ m^2$

$R = \frac{3.101 \times 10^6}{0.06283} \times 0.0254 = 1.254 \times 10^6\ N/m$

Consider 1.0 m strip

$M_r = \phi Z F_y$

$Z = \frac{bd^2}{4} = \frac{1.0 \times 0.0381^2}{4} = 3.629 \times 10^{-4}\ m^3$

$M_r = 0.9 \times 3.629 \times 10^{-4} \times 689.5 \times 10^6 = 225198\ Nm$

$M_f = \frac{R L_b}{2} = 1.254 \times 10^6 \times \frac{0.0254}{2} = 15925.8\ Nm$

$M_r > M_f$ ok

<u>S16.1 Bearing</u>

$B_r = 1.50 \phi F_y A \qquad F_y = 350 \times 10^6\ N/m^2$

$= 1.50 \times 0.9 \times 350 \times 10^6 \times 0.06283$

$= 29.687 \times 10^6\ N > 3.101 \times 10^6$ ok

Conclusions:

1) All areas of concern under yield.

2). All areas on tension side (C, D). have very low tensile stresses - will not break.

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Annex B Fabrication Drawings

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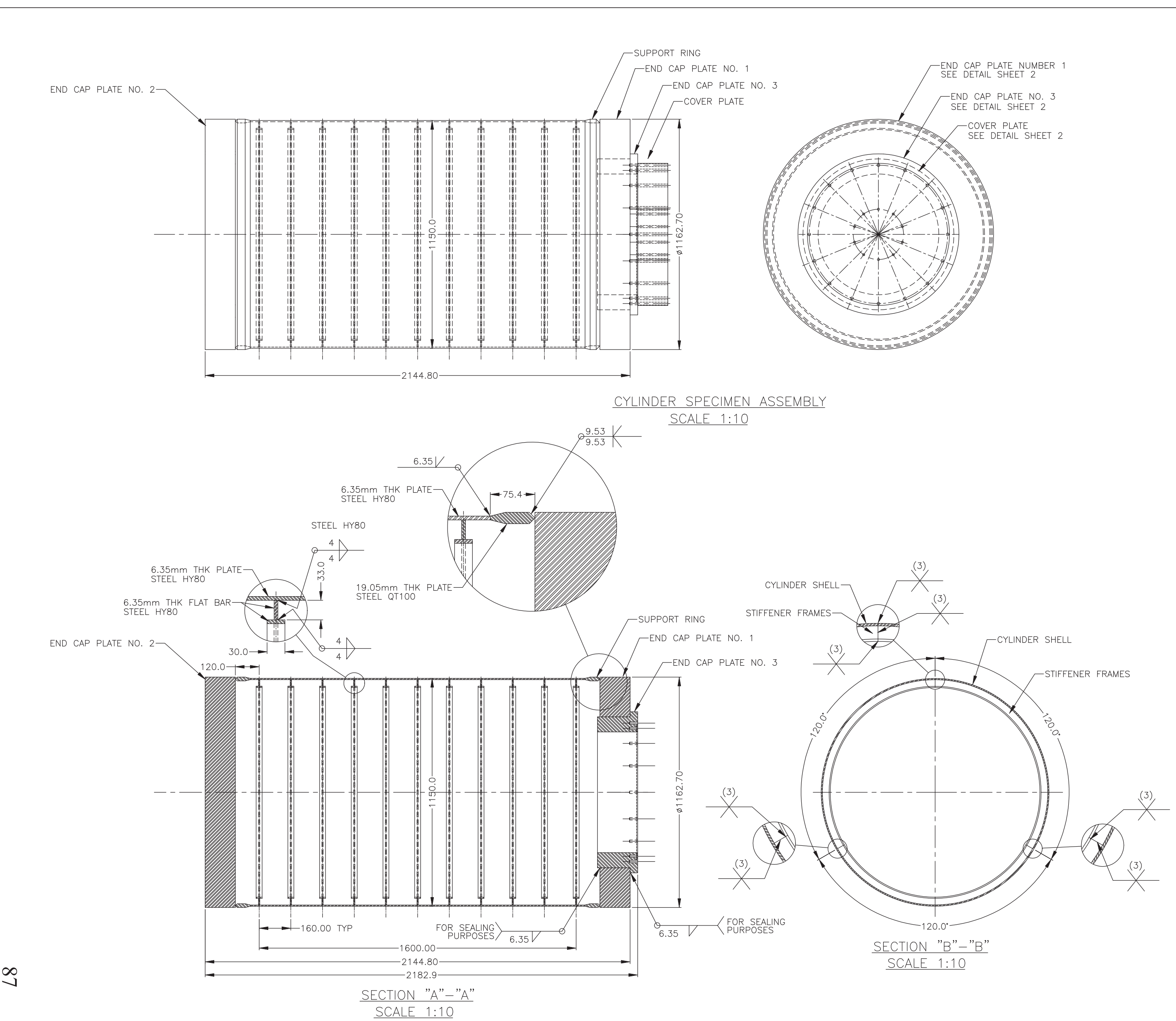


NOTES :

1: DIMENSIONS ARE IN METRIC UNITS.
2: O-RING GROVE DIMENSIONS CORRESPOND TO PARKER O-RING 2-474 AND 2-475.
3: WELD ELECTRODES MUST MATCH STRONGER MATERIAL.
4: 44W MATERIAL MUST HAVE MILL CERTIFICATION OF 50ksi.
5: SURFACE FINISH 12"ø OF END CAP COVER PLATE TO 32uINCH.Ra
6: SURFACE FINISH OUTER 6"ø OF END CAP COVER PLATE TO 32uINCH.Ra

DRAWING NUMBER	DRAWING TITLE
REFERENCE DRAWINGS	

REV	DATE	DESCRIPTION	BY	CHK	ENG	APP	CLT
0	03.02.11	ISSUED FOR FABRICATION	RL				

REVISIONS

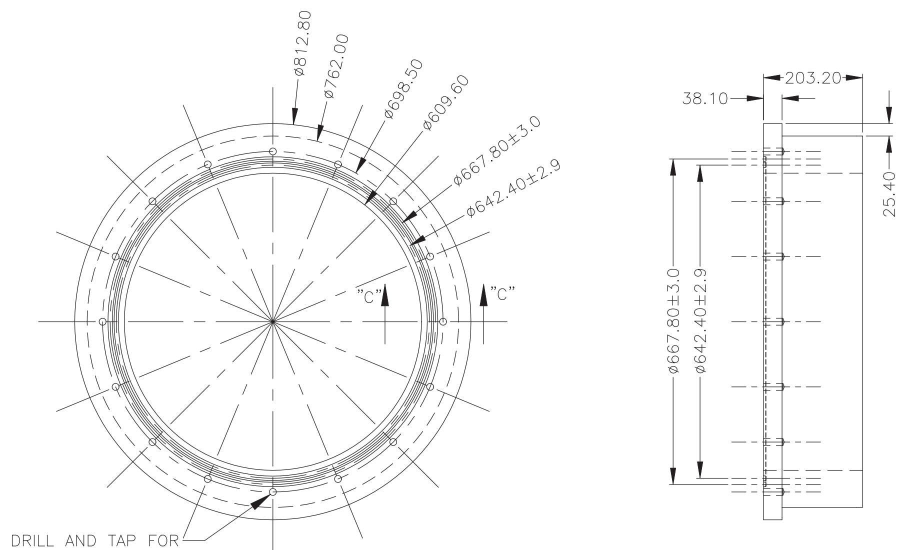
MARTEC
400, 1888 Brunswick Street, Halifax, Nova Scotia, Canada, B3J 3J8

CLIENT :

PROJECT :

TITLE :
CYLINDER SPECIMEN ASSEMBLY AND DETAILS

DCN No.	DRAWING NUMBER	REVISION
SHT 1 OF 3	2010-001	0
ORIG. SIZE Ansi D	SCALE 1:10	PROJECT No.

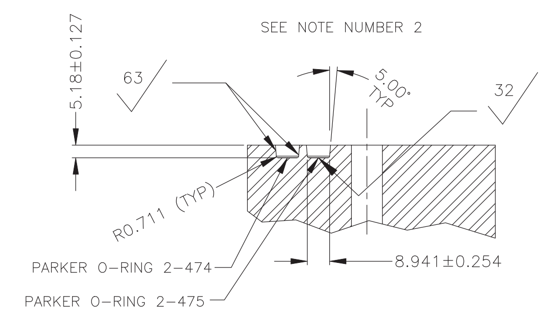


END CAP PLATE NO. 3 DETAIL

SCALE 1:5

MATERIAL: STEEL 44W

ONE IN NUMBER REQUIRED



SECTION "C"–"C"

SCALE 1:1

NOTES :

1. DIMENSIONS ARE IN METRIC UNITS.
2. O-RING GROVE DIMENSIONS CORRESPOND TO PARKER O-RING 2-474 AND 2-475.
3. WELD ELECTRODES MUST MATCH STRONGER MATERIAL.
4. 44W MATERIAL MUST HAVE MILL CERTIFICATION OF 50ksi.
5. SURFACE FINISH 12"ø OF END CAP COVER PLATE TO 32uINCH.Ra
6. SURFACE FINISH OUTER 6"ø OF END CAP COVER PLATE TO 32uINCH.Ra

DRAWING NUMBER	DRAWING TITLE

REFERENCE DRAWINGS

REV	DATE	DESCRIPTION	BY	CHK	ENG	APP	CLT
0	03.02.11	ISSUED FOR FABRICATION	RL				

REVISIONS

MARTEC

400, 1888 Brunswick Street, Halifax, Nova Scotia, Canada, B3J 3J8

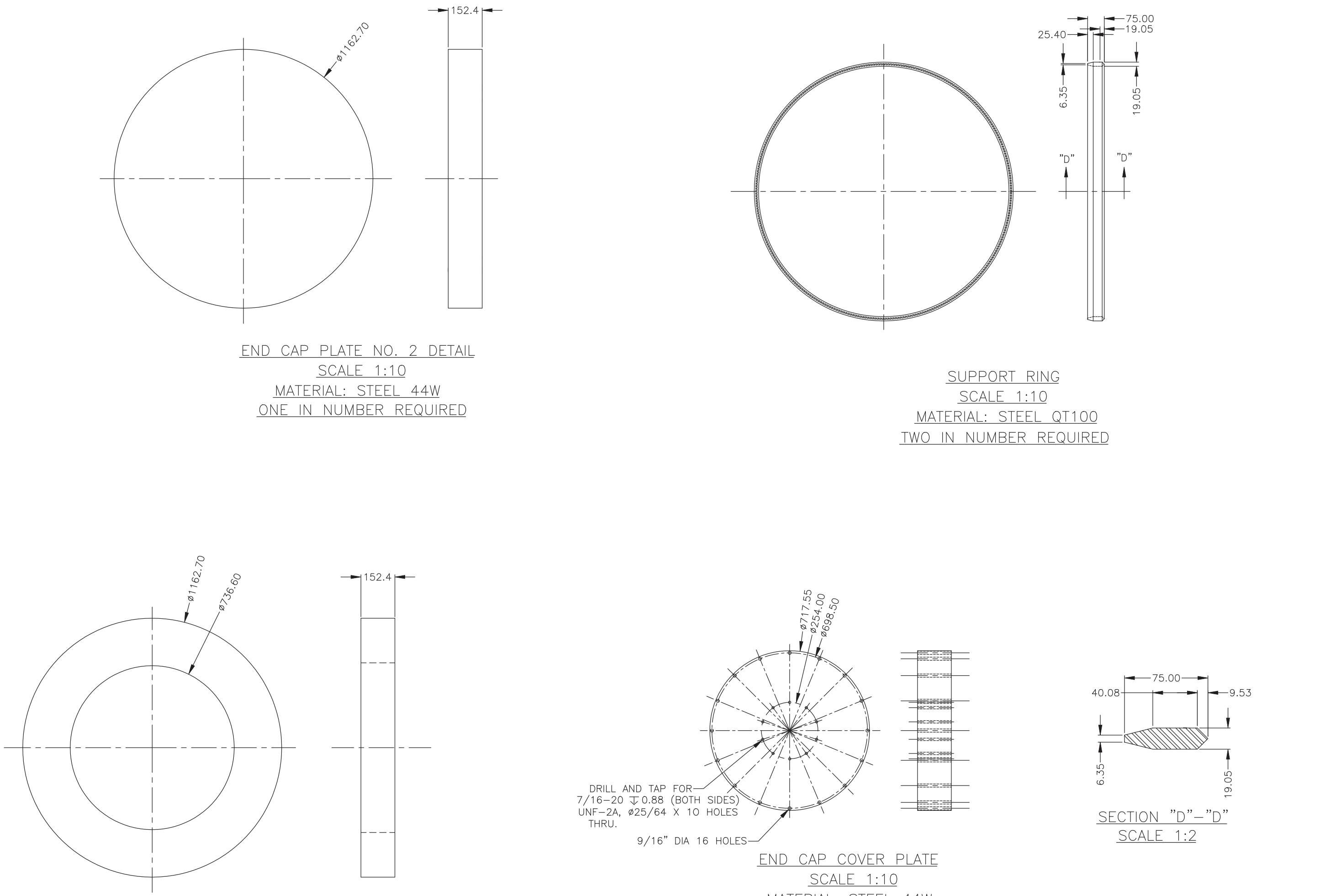
CLIENT :

PROJECT :

TITLE :

CYLINDER SPECIMEN ASSEMBLY AND DETAILS

DCN No.	DRAWING NUMBER	REVISION
SHT 3 OF 3	2010–001	0
ORIG. SIZE Ansi D	SCALE AS NOTED	PROJECT No.



END CAP PLATE NO. 2 DETAIL
SCALE 1:10
MATERIAL: STEEL 44W
ONE IN NUMBER REQUIRED

SUPPORT RING
SCALE 1:10
MATERIAL: STEEL QT100
TWO IN NUMBER REQUIRED

END CAP PLATE NO. 1 DETAIL
SCALE 1:10
MATERIAL: STEEL 44W
ONE IN NUMBER REQUIRED

END CAP COVER PLATE
SCALE 1:10
MATERIAL: STEEL 44W
ONE IN NUMBER REQUIRED

SECTION "D"–"D"
SCALE 1:2

NOTES :

1: DIMENSIONS ARE IN METRIC UNITS.
2: O-RING GROVE DIMENSIONS CORRESPOND TO PARKER O-RING 2-474 AND 2-475.
3: WELD ELECTRODES MUST MATCH STRONGER MATERIAL.
4: 44W MATERIAL MUST HAVE MILL CERTIFICATION OF 50ksi.
5: SURFACE FINISH 12"ø OF END CAP COVER PLATE TO 32uINCHRa
6: SURFACE FINISH OUTER 6"ø OF END CAP COVER PLATE TO 32uINCHRa

DRAWING NUMBER	DRAWING TITLE

REFERENCE DRAWINGS

REV	DATE	DESCRIPTION	BY	CHK	ENG	APP	CLT
0	03.02.11	ISSUED FOR FABRICATION	RL				

REVISIONS

MARTEC

400, 1888 Brunswick Street, Halifax, Nova Scotia, Canada, B3J 3J8

CLIENT :

PROJECT :

TITLE :

CYLINDER SPECIMEN ASSEMBLY AND DETAILS

DCN No.	DRAWING NUMBER	REVISION
SHT 2 OF 3	2010–001	0
ORIG. SIZE Ansi D	SCALE AS NOTED	PROJECT No.

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Annex C HY80 Weld Procedures

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Petersen's Welding

WELD PROCEDURE SPECIFICATION

Company Name: Petersen's Welding   By: ____
Weld Procedure Specification No: WPS HY80   Date: June 2, 2009   Supporting PQR No(s): ____
Revision No: ____   Date: ____   PQR Revision(s): ____
Purpose of Revision: ____
Welding Process(es): GMAW   Types: Manual
Title: MIL-S-16215K HY80 to MIL-S-16215K HY80

JOINTS (QW-402)

Details
Weld procedure will be used for fillet welds on T-frames and for cap pass on shell seam weld.

Joint Design: All Typical ASME Joint Designs
Backing (Yes): X   (No): X
Backing Material (Type): Base or weld metal where applicable
Metal X   Nonfusing Metal ____
Other ____   Nonmetallic ____

BASE METALS (QW-403)

P-No: ---   Gp No: ---   to P-No: ---   Gp No: ---
OR
Specifiction Type and Grade: MIL-S-16215K HY80
to Specification Type and Grade: MIL-S-16215K HY80
OR
Chem. Analysis and Mech. Prop. ____
to Chem. Analysis and Mech. Prop. ____
THICKNESS RANGE:
Base Metal: Groove: 0.062 to 0.750" pipe base metal to 0.188" to 3" plate base metal
Pipe Dia. Range: Groove: Unlimited   Fillet: All
Other: Maximum thickness of any weld layer should not exceed 0.500"

FILLER METAL (QW-404)

Process	GMAW	
Spec No. (SFA)	5.28	
AWS No. (Class)	ER100S-1	
F-No.		
A-No.		
Size of Filler Metals	0.035"	
Weld Metal Name Thickness Range: Groove:	0.100" max.	
Fillet:	Unlimited	
Electrode - Flux (Class)	N/A	
Flux Trade Name	N/A	
Consumable Insert	N/A	
Other	Cold Solid Wire	

WPS No. WP305 Revision 1

POSITIONS (QW-405)		POSTWELD HEAT TREATMENT (QW-407	
Positions of Groove:	All position	Heating Rate:	
Welding Progression:	Up X Down X	Temperature Range:	
Positon(s) of Fillet	All	Time Range:	
		Cooling Rate:	

PREHEAT (QW-406)	
Preheat Temp.	None < 1", over 1" is 175 ^{o} F, over 2" is 250º F
Interpass Temp. Max:	350^{o} F
Method:	Propane, oxy-acetylene, induction
Other:	Monitor using tempsticks or other suitable method

GAS (QW-408)

	Gas(es)	Percent Composition (Mixture)	Flow Rate
Shielding	90% Argon/10% CO2	Weld Grade	30 cfh
Trailing	None		
Backing	None		
Other			

ELECTRICAL CHARACTERISTICS (QW-409)

Current AC or DC:	DC	Polarity:	GMAW: Straight
Amps (Range):	GMAW: 180-240	Volts (Range):	GMAW: 23-26

Tungsten Electrode Size and Type:	N/A
Mode of Metal Transfer for GMAW:	Spray transfer
Electrode Wire feed speed range:	400 - 500 ipm

TECHNIQUE (QW-410)

String or Weave Bead:	String or Weave
Orifice or Gas Cup Size	3/8" to 3/4"
Initial and Interpass Cleaning:	Brushing, grinding and/or chipping.
Method of Back Gouging:	Arc air, gouge, grind, etc.
Oscillation:	N/A
Contact Tube to Work Distance:	½"
Multiple or Single Pass (per side):	Multiple
Multiple or Single Electrode:	Single
Peening:	None
Other	

		Filler Metal		Current				
Weld Layer(s)	Process	Class	Dia.	Type Polarity	Amp. Range	Volt Range	Travel Speed Range	Other Remarks
1	GMAW	ER100S-1	0.035"	DCSP	180-240	23-26	12-24 IPM	

Petersen's Welding

WELD PROCEDURE SPECIFICATION

Company Name: Petersen's Welding   By: ____
Weld Procedure Specification No: WPS HY80   Date: June 2, 2009   Supporting PQR No(s): ____
Revision No: ____   Date: ____   PQR Revision(s): ____
Purpose of Revision: ____
Welding Process(es): GMAW   Types: Manual
Title: MIL-S-16215K HY80 to MIL-S-16215K HY80

JOINTS (QW-402)

Details
Weld procedure will be used to tack assemblies, splice webs on T-frames, and root pass for seam weld on shell.

Joint Design: All Typical ASME Joint Designs
Backing (Yes): X   (No): X
Backing Material (Type): Base or weld metal where applicable
Metal X   Nonfusing Metal ____
Other ____   Nonmetallic ____

BASE METALS (QW-403)

P-No: ---   Gp No: ---   to P-No: ---   Gp No: ---
OR
Specifiction Type and Grade: MIL-S-16215K HY80
to Specification Type and Grade: MIL-S-16215K HY80
OR
Chem. Analysis and Mech. Prop. ____
to Chem. Analysis and Mech. Prop. ____
THICKNESS RANGE:
Base Metal: Groove: 0.062 to 0.750" pipe base metal to 0.188" to 3" plate base metal
Pipe Dia. Range: Groove: Unlimited   Fillet: All
Other: Maximum thickness of any weld layer should not exceed 0.500"

FILLER METAL (QW-404)

Process	GMAW	
Spec No. (SFA)	5.28	
AWS No. (Class)	ER100S-1	
F-No.		
A-No.		
Size of Filler Metals	0.035"	
Weld Metal Name Thickness Range: Groove:	0.100" max.	
Fillet:	Unlimited	
Electrode - Flux (Class)	N/A	
Flux Trade Name	N/A	
Consumable Insert	N/A	
Other	Cold Solid Wire	

WPS No. WP305 Revision 1

POSITIONS (QW-405)		POSTWELD HEAT TREATMENT (QW-407	
Positions of Groove:	All position	Heating Rate:	
Welding Progression:	Up X Down X	Temperature Range:	
Positon(s) of Fillet	All	Time Range:	
		Cooling Rate:	

PREHEAT (QW-406)	
Preheat Temp.	None < 1", over 1" is 175 ^{o} F, over 2" is 250º F
Interpass Temp. Max:	350^o F
Method:	Propane, oxy-acetylene, induction
Other:	Monitor using tempsticks or other suitable method

GAS (QW-408)

	Gas(es)	Percent Composition (Mixture)	Flow Rate
Shielding	90% Argon/10% CO2	Weld Grade	30 cfh
Trailing	None		
Backing	None		
Other			

ELECTRICAL CHARACTERISTICS (QW-409)

Current AC or DC:	DC	Polarity:	GMAW: Straight
Amps (Range):	GMAW: 60-180	Volts (Range):	GMAW: 18-21

Tungsten Electrode Size and Type:	N/A
Mode of Metal Transfer for GMAW:	Short circuit,
Electrode Wire feed speed range:	250 - 300 ipm

TECHNIQUE (QW-410)

String or Weave Bead:	String or Weave
Orifice or Gas Cup Size	3/8" to 3/4"
Initial and Interpass Cleaning:	Brushing, grinding and/or chipping.
Method of Back Gouging:	Arc air, gouge, grind, etc.
Oscillation:	N/A
Contact Tube to Work Distance:	½"
Multiple or Single Pass (per side):	Multiple
Multiple or Single Electrode:	Single
Peening:	None
Other	

Weld Layer(s)	Process	Filler Metal Class	Filler Metal Dia.	Current Type Polarity	Current Amp. Range	Volt Range	Travel Speed Range	Other Remarks
1	GMAW	ER100S-1	0.035"	DCSP	60-180	18-21	6-12 IPM	

Annex D HY80 Plate Mill Certificates

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Ronson Technical Products Division
ENERGY & PROCESS CORP.
2146-B Flintstone Drive
Tucker, GA 30084-5000
Phone: (770) 414-8488
FAX: (770) 621-9660
WATS: (800) 524-0698

CERTIFICATE OF COMPLIANCE

THIS IS TO CERTIFY THAT THE MATERIAL SHIPPED IS IN COMPLIANCE WITH THE REFERENCED SPECIFICATIONS AND YOUR PURCHASE ORDER REQUIREMENTS.

ORIGINAL TEST REPORTS ARE MAINTAINED IN OUR FILES.

YOUR PURCHASE ORDER: CT5807

PURCHASE ORDER DATE: 9-9-10

RONSON SALES ORDER: RE-9887

SHIPPED TO: C-FER TECNOLOGIES (1999) INC
200 KARL CLARK RD
EDMONTON, ALBERTA
CANADA, T6N 1H2

REPORT OF CHEMICAL AND PHYSICAL TEST TO: MIL-S-16216K HY80 TY.1

DESCRIPTION: ITEM 1: 3PCS ¼" X 96" X 240" PLATE
CUT PER DRAWING CFER-F034-07
ARCELORMITTAL
1PC HT# R2452-01AB
1PC HT# R2452-01AC
1PC HT# R2452-01AD

THIS MATERIAL HAS NOT COME INTO CONTACT WITH MERCURY OR ANY OF ITS COMPOUNDS WHILE IN OUR POSSESSION.

JIM COYER
QUALITY ASSURANCE DEPT.

September 22, 2010
DATE

Ronson Technical Products Division
ENERGY & PROCESS CORP.
2146-B Flintstone Drive
Tucker, GA 30084-5000
Phone: (770) 414-8488
FAX: (770) 621-9660
WATS: (800) 524-0698

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ARCELORMITTAL
1PC HT# R2452-01AB
1PC HT# R2452-01AC
1PC HT# R2452-01AD

THIS MATERIAL HAS NOT COME INTO CONTACT WITH MERCURY OR ANY OF ITS COMPOUNDS WHILE IN OUR POSSESSION.

Jim Coyer

JIM COYER
QUALITY ASSURANCE DEPT.

September 22, 2010
DATE

ORIGINAL 411006

ARCELORMITTAL PLATE LLC

TEST CERTIFICATE

PAGE NO: 01 OF 03
FILE NO: 2822-01-02
MILL ORDER NO: 31350-001
MELT NO: R2452
SLAB NO: 1AD
DATE: 05/25/10

SHIP TO:
RONSON TECHNICAL PRODUCTS
C/O HUDSON METAL PROCESSING
1500 NATIONAL CEMETARY ROAD
FLORENCE SC 29506

SOLD TO:
ENERGY & PROCESS CORPORATION
A FERGUSON ENTERPRISE
P.O. BOX 125
TUCKER GA 30085-0125

SEND TO:

01-C

PLATE DIMENSIONS / DESCRIPTION

TOTAL QTY	GAUGE	WIDTH	LENGTH	DESCRIPTION	PIECE WEIGHT
1	1/4"	96"	240"	RECTANGLE	1634#

CUSTOMER INFORMATION

CUSTOMER PO: E257-451

CONTRACT NO. CD8-46079-08 PART NO. HY8014N

SPECIFICATION(S)

THIS MATERIAL HAS BEEN MANUFACTURED AND TESTED IN ACCORDANCE WITH PURCHASE ORDER REQUIREMENTS AND SPECIFICATION(S).

NAVSE TECH-PUB-T9074 REV 0 YR 02 HY80-TY.I
MIL S-16216K(SH) 87 GRADE HY80 TYPE I
NAVSEA TECH. PUBLICATION T9074-BD-GIB-010/0300
REVISION 0 DATED 08/09/02 HY80-TYI
WITH ACN 1 OF 11 DEC. 2002.
THE MANAGEMENT SYSTEMS FOR MANUFACTURE OF THIS PRODUCT ARE CERTIFIED TO ISO 9001:2000 (CERTIFICATE NO. 30130) AND ISO 14001 (CERTIFICATE NO. 006928).

CHEMICAL COMPOSITION

	C	MN	P	S	CU	SI	NI	CR	MO
MELT:R2452	.13	.31	.005	.002	.14	.20	2.16	1.11	.24
PROD ANALYSIS	.12	.30	.004	.002	.13	.20	2.06	1.07	.22

	V	TI	AL	CB	SB	AS	SN
MELT:R2452	.003	.001	.016	.001	.0010	.0030	.007
PROD ANALYSIS	.003	.001	.018	.001	.0010	.0030	.005

MANUFACTURE

ELECTRIC FURNACE QUALITY - FINELINE - VACUUM DEGASSED - FINE GRAIN PRACTICE

Q.A. APPROVED
RONSON TECHNICAL PRODUCTS
Charles Wolf

WE HEREBY CERTIFY THE ABOVE INFORMATION IS CORRECT:

ARCELORMITTAL PLATE LLC
QUALITY ASSURANCE LABORATORY
139 MODENA ROAD
COATESVILLE, PA 19320

Elinore Zaplitny
SUPERVISOR – TEST REPORTING
ELINORE ZAPLITNY

101

411006

TEST CERTIFICATE

PAGE NO: 02 OF 03
FILE NO: 2822-01-02
MILL ORDER NO: 31350-001
MELT NO: R2452
SLAB NO: 1AD
DATE: 05/25/10

HEAT TREAT CONDITION

MATL OR TEST	HEAT TREAT DESCRIPTION	NOM TEMP	HOLD MINS	COOL MTHD
PL/TEST	HARDEN	1659F	16	W.QUENCH
PL/TEST	TEMPER	1280F	27	AIR COOL

TENSILE PROPERTIES

SLAB NO.	LOC	DIR	YIELD STRENGTH PSI X 100	TENSILE STRENGTH PSI X 100	ELONGATION GAGE LGTH	%
1AD	BOT.	TRANS.	972	1063	2.00"	28.0
1AD	TOP	TRANS.	949	1046	2.00"	28.0

WE HEREBY CERTIFY THE ABOVE
INFORMATION IS CORRECT:

ARCELORMITTAL PLATE LLC
QUALITY ASSURANCE LABORATORY
139 MODENA ROAD
COATESVILLE, PA 19320

Elinore Zaplitny
SUPERVISOR – TEST REPORTING
ELINORE ZAPLITNY

4 1 1 0 0 6

TEST CERTIFICATE

PAGE NO: 03 OF 03
FILE NO: 2822-01-02
MILL ORDER NO: 31350-001
MELT NO: R2452
SLAB NO: 1AD
DATE: 05/25/10

GENERAL INFORMATION

ALL STEEL HAS BEEN MELTED AND MANUFACTURED IN THE U.S.A.
PRODUCED IN ACCORDANCE WITH INSPECTION SYSTEM
REQUIREMENTS OF MIL-I-45208A AMEND #1.
MATERIAL HAS BEEN VACUUM DEGASSED AND CALCIUM TREATED
FOR SULFIDE SHAPE CONTROL. FINELINE MOD FOR SULPHUR
NO WELD REPAIR PERFORMED BY ARCELORMITTAL PLATE LLC.
THE TEST RESULTS SHOWN IN THIS REPORT ARE THE
RESULTS OF TESTING PERFORMED BY OUR ORGANIZATION.
LOW MELTING ALLOYS OR LOW MELTING COMPOUNDS ARE NOT
USED IN THE MANUFACTURE OF ARCELORMITTAL PLATE LLC
PRODUCTS OTHER THAN AS DEOXIDIZING AGENTS.
MERCURY OR MERCURY COMPOUNDS ARE NOT USED IN THE
MANUFACTURE OF ARCELORMITTAL PLATE LLC PRODUCTS.

NDT, VISUAL AND DIMENSIONAL INSPECTION AS REQUIRED BY THE SPECIFICATION WAS SATISFACTORILY PERFORMED.

MATERIAL HAS BEEN SAMPLED, TESTED, AND INSPECTED IN ACCORDANCE WITH THE SPECIFICATION REQUIREMENTS. THE MANUFACTURER HAS MAINTAINED MANUFACTURING PROCEDURES AND PRACTICES WHICH PRODUCE PLATES WHICH MEET THE MINIMUM PROPERTY REQUIREMENTS THROUGHOUT THE PLATE. THE MATERIAL MEETS ALL SPECIFICATION REQUIREMENTS.

RECORDS ARE AVAILABLE COVERING HEAT NUMBER OF THE MATERIAL USED, PROCESSING OF PLATE, DIMENSIONAL CONTROL EMPLOYED AND HEAT TREATMENT.

KNOWINGLY AND WILLFULLY FALSIFYING OR CONCEALING A MATERIAL FACT ON THIS FORM, OR MAKING FALSE, FICTITIOUS OR FRAUDULENT ENTRIES OR REPRESENTATIONS HEREIN, COULD CONSTITUTE A FELONY PUNISHABLE UNDER FEDERAL STATUTES.

CERTIFICATE OF CONFORMANCE - ALL ITEMS FURNISHED IN THE SHIPMENT ARE IN FULL CONFORMANCE WITH ALL P.O. AND SPEC. REQ.; AND THAT THE T.R.'S REPRESENT THE ACTUAL ATTRIBUTES OF THE ITEMS FURNISHED ON THE ORDER, AND THAT THE TEST RESULTS ARE IN FULL CONFORMANCE WITH ALL P.O. & SPEC. REQ. RECORDS TO SUBSTANTIATE THE ABOVE ARE ON FILE IN

OUR PLANT AND WILL BE MAINTAINED FOR A PERIOD OF 7 YRS. FROM THE DATE OF THE SHIPMENT UNLESS FURNISHED TO THE PURCHASER IN ADVANCE OF OR AT TIME OF SHIPMENT. WHEN RECORDS ARE RETAINED BY US, WE AGREE TO FURNISH SAME TO THE PURCHASER AT ANY TIME DURING THE ABOVE PERIOD UPON REQUEST.

HEAT TREAT PROC. NO. MIL-STD-1684D

B/L #11522 JONES MOTOR CO.

WE HEREBY CERTIFY THE ABOVE INFORMATION IS CORRECT:

ARCELORMITTAL PLATE LLC
QUALITY ASSURANCE LABORATORY
139 MODENA ROAD
COATESVILLE, PA 19320

Elinore Zaplitny

SUPERVISOR – TEST REPORTING
ELINORE ZAPLITNY

411006

ArcelorMittal USA

Ultrasonic (Thickness and Internal Soundness)
Micrometer, Brinell, and Plate Inspection Report

Customer	Mill Order No.	Item	Plate Spec.	Date
#2822	31350	001	NAVSE TECH-PUB-T9074 002 HY80-TY1	5-12-10
	Customer P.O. No.: E257-451	Size: .250 X 96 X 240	Melt & Slab: R2452-1AD	
N.D.T. Procedure		Mark No.	Assigned No.: 1702	

INTERNAL SOUNDNESS

Over ½" Thru 2 ½"
- ☐ Static Test on 24" Centers
- ☐ 100%

Over 2 ½"
- ☐ Grid & 1 Diagonal 24" Centers
- ☐ Static Test on 8"
- ☐ 100%
- ☐ Other

THICKNESS
ULTRASONIC THICKNESS CHECK ON 2' CENTERS STARTING 6" FROM PLATE EDGE. MICROMETER THICKNESS CHECK, THREE EACH SIDE, TWO EACH END, ALL EQUALLY SPACED.

ULTRASONIC	MICROMETER	0.5'	2.5'	4.5'	6.5'	8.5'	10.5'	12.5'	14.5'	MICROMETER
		268		271						
0.5'		"T"								
2.5'	264									
4.5'						264				
6.5'										
8.5'										
10.5'										
12.5'	260					262				
14.5'										
16.5'										
18.5'										
20.5'										
22.5'										
24.5'	267					273				
26.5'										
28.5'			271		275					
30.5'										
32.5'										
34.5'										
36.5'										
38.5'										
40.5'										
42.5'										
44.5'										
46.5'										
48.5'										

MICROMETER — "T" = Reference Thickness Starting Point — MICROMETER

VISUAL	THICKNESS	SOUNDNESS
☑ TOP ☑ BOTTOM ☑ EDGES	Instr. Mfr/Model/No. C-3; Plate Gauge ☑ Satis ☐ Unsatis	Instr. Mfr/Model/No.; Crystal (Straight Beam) 2.25 MHz 1" Dia.
Flat ☑ Within ____	Min Allow 240 Found 262	☐ Satis ☐ Unsatis; Couplant:
Camber OK ☑ Within ____	Max Allow 277AVG Found 275	Supple. Sheet Req. ☐ Yes ☐ No
Length 240-5/8, 240-1/2; Width 96-7/16, 96-1/2, 96-7/16	Remarks: OK Per Spec.	Inspector (LEVEL II SNT-TC-1A) [signature]
Brinell Hardness (1) (2) 104 (AVG)		Inspection Supervisor (LEVEL II SNT-TC-1A) [signature]

Ronson Technical Products

RECEIVING INSPECTION REPORT

Shipper #BT11522

VENDOR	PO #	INSPECTED BY
Arcelormittal Plate LLC	E257-451 F257-235, -254	[illegible]

LOCATION	VIA	DATE
Conshohocken, PA. 19428	Jones Motor Co.	5-25-10

ITEM	SPECIFICATION	QUAN.	SIZE	HEAT/LOT - SLAB	STOCK #	COLOR CODE	COST
1	HY80 Ty. I	1	1/4X96X240	R2452-01AD	411006		
2	AH/DH36	1	3/16X96X480	R4292-39C	261680		
3		1	3/16X96X480	R4292-39C	261681		
4		1	3/16X96X480	R4292-39C	261682		
5		1	3/16X96X480	R4292-39C	261683		
6		1	3/16X96X480	R4292-39C	261684		
7	HSLA 100 Ty. 2	1	5/8X96X480	R4705-39CA	510092		
8	HSLA 100 Ty. 2	1	3/4X96X480	R4705-01AA	510093		
9	HSLA 100 Ty. I	1	1/2X96X480	R4553-01FB	510090		
10		1	1/2X96X480	R5008-39AA	510091		

STOCK

CUSTOMER

S.O. #

COMMENTS

QA DOCUMENTS RECEIVED 44,921#

QA REVIEW BY

QA RELEASE BY | DATE | DMR #

COMMENTS

410930

ARCELORMITTAL PLATE LLC

TEST CERTIFICATE

SHIP TO:
RONSON TECHNICAL PRODUCTS
C/O HUDSON METAL PROCESSING
1500 NATIONAL CEMETARY ROAD
FLORENCE SC 29506

ORIGINAL

PAGE NO: 01 OF 03
FILE NO: 2822-01-02
MILL ORDER NO: 31350-001
MELT NO: R2452
SLAB NO: 1AB
DATE: 11/26/09

SOLD TO:
ENERGY & PROCESS CORPORATION
A FERGUSON ENTERPRISE
P.O. BOX 125
TUCKER GA 30085-0125

SEND TO:

01-C

PLATE DIMENSIONS / DESCRIPTION

TOTAL QTY	GAUGE	WIDTH	LENGTH	DESCRIPTION	PIECE WEIGHT
1	1/4"	96"	240"	RECTANGLE	1634#

CUSTOMER INFORMATION

CUSTOMER PO: E257-451

CONTRACT NO. CD8-46079-08

PART NO. HY8014N

SPECIFICATION(S)

THIS MATERIAL HAS BEEN MANUFACTURED AND TESTED IN ACCORDANCE WITH PURCHASE ORDER REQUIREMENTS AND SPECIFICATION(S).

NAVSE TECH-PUB-T9074 REV 0 YR 02 HY80-TY.I
MIL S-16216K(SH) 87 GRADE HY80 TYPE I
NAVSEA TECH. PUBLICATION T9074-BD-GIB-010/0300
REVISION 0 DATED 08/09/02 HY80-TYI
WITH ACN 1 OF 11 DEC. 2002.
THE MANAGEMENT SYSTEMS FOR MANUFACTURE OF THIS PRODUCT ARE CERTIFIED TO ISO 9001:2000 (CERTIFICATE NO. 30130) AND ISO 14001 (CERTIFICATE NO. 006928).

CHEMICAL COMPOSITION

	C	MN	P	S	CU	SI	NI	CR	MO
MELT:R2452	.13	.31	.005	.002	.14	.20	2.16	1.11	.24
PROD ANALYSIS	.12	.30	.004	.002	.13	.20	2.06	1.07	.22

	V	TI	AL	CB	SB	AS	SN
MELT:R2452	.003	.001	.016	.001	.0010	.0030	.007
PROD ANALYSIS	.003	.001	.018	.001	.0010	.0030	.005

MANUFACTURE

ELECTRIC FURNACE QUALITY - FINELINE - VACUUM DEGASSED - FINE GRAIN PRACTICE

Q.A. APPROVED
RONSON TECHNICAL PRODUCTS
Charles Wolfe

WE HEREBY CERTIFY THE ABOVE INFORMATION IS CORRECT:

ARCELORMITTAL PLATE LLC
QUALITY ASSURANCE LABORATORY
139 MODENA ROAD
COATESVILLE, PA 19320

Elinore Zaplitny
SUPERVISOR - TEST REPORTING
ELINORE ZAPLITNY

410930

ORIGINAL

TEST CERTIFICATE

PAGE NO: 02 OF 03
FILE NO: 2822-01-02
MILL ORDER NO: 31350-001
MELT NO: R2452
SLAB NO: 1AB
DATE: 11/26/09

HEAT TREAT CONDITION

MATL OR TEST	HEAT TREAT DESCRIPTION	NOM TEMP	HOLD MINS	COOL MTHD
PL/TEST	HARDEN	1659F	16	W.QUENCH
PL/TEST	TEMPER	1280F	27	AIR COOL

TENSILE PROPERTIES

SLAB NO.	LOC	DIR	YIELD STRENGTH PSI X 100	TENSILE STRENGTH PSI X 100	ELONGATION GAGE LGTH	%
1AB	BOT.	TRANS.	939	1031	2.00"	30.0
1AB	TOP	TRANS.	945	1033	2.00"	27.0

WE HEREBY CERTIFY THE ABOVE INFORMATION IS CORRECT:

ARCELORMITTAL PLATE LLC
QUALITY ASSURANCE LABORATORY
139 MODENA ROAD
COATESVILLE, PA 19320

Elinore Zaplitny
SUPERVISOR – TEST REPORTING
ELINORE ZAPLITNY

410930

TEST CERTIFICATE

ORIGINAL

PAGE NO: 03 OF 03
FILE NO: 2822-01-02
MILL ORDER NO: 31350-001
MELT NO: R2452
SLAB NO: 1AB
DATE: 11/26/09

GENERAL INFORMATION

ALL STEEL HAS BEEN MELTED AND MANUFACTURED IN THE U.S.A.
PRODUCED IN ACCORDANCE WITH INSPECTION SYSTEM
REQUIREMENTS OF MIL-I-45208A AMEND #1.
MATERIAL HAS BEEN VACUUM DEGASSED AND CALCIUM TREATED
FOR SULFIDE SHAPE CONTROL. FINELINE MOD FOR SULPHUR
NO WELD REPAIR PERFORMED BY ARCELORMITTAL PLATE LLC.
THE TEST RESULTS SHOWN IN THIS REPORT ARE THE
RESULTS OF TESTING PERFORMED BY OUR ORGANIZATION.
LOW MELTING ALLOYS OR LOW MELTING COMPOUNDS ARE NOT
USED IN THE MANUFACTURE OF ARCELORMITTAL PLATE LLC
PRODUCTS OTHER THAN AS DEOXIDIZING AGENTS.
MERCURY OR MERCURY COMPOUNDS ARE NOT USED IN THE
MANUFACTURE OF ARCELORMITTAL PLATE LLC PRODUCTS.

NDT, VISUAL AND DIMENSIONAL INSPECTION AS REQUIRED BY THE SPECIFICATION WAS SATISFACTORILY PERFORMED.

MATERIAL HAS BEEN SAMPLED, TESTED, AND INSPECTED IN ACCORDANCE WITH THE SPECIFICATION REQUIREMENTS. THE MANUFACTURER HAS MAINTAINED MANUFACTURING PROCEDURES AND PRACTICES WHICH PRODUCE PLATES WHICH MEET THE MINIMUM PROPERTY REQUIREMENTS THROUGHOUT THE PLATE. THE MATERIAL MEETS ALL SPECIFICATION REQUIREMENTS.

RECORDS ARE AVAILABLE COVERING HEAT NUMBER OF THE MATERIAL USED, PROCESSING OF PLATE, DIMENSIONAL CONTROL EMPLOYED AND HEAT TREATMENT.

KNOWINGLY AND WILLFULLY FALSIFYING OR CONCEALING A MATERIAL FACT ON THIS FORM, OR MAKING FALSE, FICTITIOUS OR FRAUDULENT ENTRIES OR REPRESENTATIONS HEREIN, COULD CONSTITUTE A FELONY PUNISHABLE UNDER FEDERAL STATUTES.

CERTIFICATE OF CONFORMANCE - ALL ITEMS FURNISHED IN THE SHIPMENT ARE IN FULL CONFORMANCE WITH ALL P.O. AND SPEC. REQ.; AND THAT THE T.R.'S REPRESENT THE ACTUAL ATTRIBUTES OF THE ITEMS FURNISHED ON THE ORDER, AND THAT THE TEST RESULTS ARE IN FULL CONFORMANCE WITH ALL P.O. & SPEC. REQ. RECORDS TO SUBSTANTIATE THE ABOVE ARE ON FILE IN

OUR PLANT AND WILL BE MAINTAINED FOR A PERIOD OF 7 YRS. FROM THE DATE OF THE SHIPMENT UNLESS FURNISHED TO THE PURCHASER IN ADVANCE OF OR AT TIME OF SHIPMENT. WHEN RECORDS ARE RETAINED BY US, WE AGREE TO FURNISH SAME TO THE PURCHASER AT ANY TIME DURING THE ABOVE PERIOD UPON REQUEST.

HEAT TREAT PROC. NO. MIL-STD-1684D

B/L #77808 JONES MOTOR CO.

WE HEREBY CERTIFY THE ABOVE INFORMATION IS CORRECT:

ARCELORMITTAL PLATE LLC
QUALITY ASSURANCE LABORATORY
139 MODENA ROAD
COATESVILLE, PA 19320

Elinore Zaplitny

SUPERVISOR - TEST REPORTING
ELINORE ZAPLITNY

ORIGINAL

410930

Form No. 1360 (R 4/09)

ArcelorMittal USA

Ultrasonic (Thickness and Internal Soundness) Micrometer, Brinell, and Plate Inspection Report

Customer	Mill Order No.	Item	Plate Spec.	Date
2822	31350	001	NAUSE Tech Pub T9074-0-02-HY80-TYI	10/2/09
	Customer P.O. No. E257-451	Size .250 X96 X240		Melt & Slab R2452-1AB
N.D.T. Procedure		Mark No.		Assigned No. LC# 1700

INTERNAL SOUNDNESS

Over ½" Thru 2 ½"
- ☐ Static Test on 24" Centers
- ☐ 100%

Over 2 ½"
- ☐ Grid & 1 Diagonal 24" Centers
- ☐ Static Test on 8"
- ☐ Other

THICKNESS

ULTRASONIC THICKNESS CHECK ON 2' CENTERS STARTING 6" FROM PLATE EDGE, MICROMETER THICKNESS CHECK, THREE EACH SIDE, TWO EACH END, ALL EQUALLY SPACED.

ULTRASONIC / MICROMETER	MICROMETER	0.5'	2.5'	4.5'	6.5'	8.5'	10.5'	12.5'	14.5'	MICROMETER
0.5'				265	268					
2.5'		265 "T"								
4.5'							264			
6.5'										
8.5'										
10.5'		266								
12.5'							264			
14.5'										
16.5'		264								
18.5'							266			
20.5'										
22.5'				265	267					
24.5'										
26.5'										
28.5'										
30.5'										
32.5'										
34.5'										
36.5'										
38.5'										
40.5'										
42.5'										
44.5'										
46.5'										
48.5'										

MICROMETER

"T" = Reference Thickness Starting Point

MICROMETER

VISUAL

☑ TOP ☑ BOTTOM ☑ EDGES

Flat ☑ Within 3/4

Camber OK ☑ Within 1/4

Length 240 3/4, 240 11/16

Width 96 1/2, 96 9/16, 96 7/16

Brinell Hardness

(1) (2) (AVG)

THICKNESS

Instr. Mfr/Model/No. C6

Plate Gauge ☑ Satis ☐ Unsatis

Min Allow .240 Found .264

Max Allow .277 .276 Found .268

Remarks:

SOUNDNESS

Instr. Mfr/Model/No.

☐ Satis. ☐ Unsatis

Crystal (Straight Beam)

2.25 MHz 1" Dia.

Couplant:

Supple. Sheet Req. ☐ Yes ☐ No

Inspector (LEVEL 1 SNT-TC-1A)

Inspection Supervisor (LEVEL II ...)

Ronson Technical Products
RECEIVING INSPECTION REPORT

VENDOR: Arcelormittal Plate LLC

PO #: E257-451, -381 Add#1, -451 Add#1

Shipper # BT77808

LOCATION: Conshohocken, PA

VIA: Jones Motor Co.

INSPECTED BY: Dennis Hudson

DATE: 12-1-09

ITEM	SPECIFICATION	QUAN.	SIZE	HEAT/LOT - SLAB	STOCK #	COLOR CODE	COST
1	HY80-TY.1	1	1/4X96X240	R2452-01AA	410929		
2		1	1/4X96X240	R2452-01AB	410930		
3		1	1/4X96X240	R2490-39AJ	410931		
4	EH36T	1	3/8X96X480	R2339-02FA	310525		
5		1	3/8X96X480	R2339-02FB	310526		
6		1	3/8X96X480	R2339-02FC	310523		
7		1	3/8X96X480	R2651-01CA	310528		
8		1	3/8X96X480	R2651-01DA	310524		
9		1	3/8X96X480	R2651-01DC	310522		
10	HY80-Ty.1	1	1/2X96X480	R2490-04GA	410941		
11		1	1/2X96X480	R2490-04GB	410942		

STOCK

CUSTOMER

S.O. #

COMMENTS

QA DOCUMENTS RECEIVED

QA REVIEW BY

47,376#

QA RELEASE BY

DATE

COMMENTS

DMR #

410935

ORIGINAL

TEST CERTIFICATE

ARCELORMITTAL PLATE LLC

PAGE NO: 01 OF 03
FILE NO: 2822-01-02
MILL ORDER NO: 31350-001
MELT NO: R2452
SLAB NO: 1AC
DATE: 02/09/10

SHIP TO:
RONSON TECHNICAL PRODUCTS
C/O HUDSON METAL PROCESSING
1500 NATIONAL CEMETARY ROAD
FLORENCE SC 29506

SOLD TO:
ENERGY & PROCESS CORPORATION
A FERGUSON ENTERPRISE
P.O. BOX 125
TUCKER GA 30085-0125

SEND TO:

01-C

PLATE DIMENSIONS / DESCRIPTION

TOTAL QTY	GAUGE	WIDTH	LENGTH	DESCRIPTION	PIECE WEIGHT
1	1/4"	96"	240"	RECTANGLE	1634#

CUSTOMER INFORMATION

CUSTOMER PO: E257-451

CONTRACT NO. CD8-46079-08 PART NO. HY8014N

SPECIFICATION(S)

THIS MATERIAL HAS BEEN MANUFACTURED AND TESTED IN ACCORDANCE WITH PURCHASE ORDER REQUIREMENTS AND SPECIFICATION(S).

NAVSE TECH-PUB-T9074 REV 0 YR 02 HY80-TY.I
MIL S-16216K(SH) 87 GRADE HY80 TYPE I
NAVSEA TECH. PUBLICATION T9074-BD-GIB-010/0300
REVISION 0 DATED 08/09/02 HY80-TYI
WITH ACN 1 OF 11 DEC. 2002.
THE MANAGEMENT SYSTEMS FOR MANUFACTURE OF THIS PRODUCT ARE CERTIFIED TO ISO 9001:2000 (CERTIFICATE NO. 30130) AND ISO 14001 (CERTIFICATE NO. 006928).

CHEMICAL COMPOSITION

	C	MN	P	S	CU	SI	NI	CR	MO
MELT:R2452	.13	.31	.005	.002	.14	.20	2.16	1.11	.24
PROD ANALYSIS	.12	.30	.004	.002	.13	.20	2.06	1.07	.22

	V	TI	AL	CB	SB	AS	SN
MELT:R2452	.003	.001	.016	.001	.0010	.0030	.007
PROD ANALYSIS	.003	.001	.018	.001	.0010	.0030	.005

MANUFACTURE

ELECTRIC FURNACE QUALITY - FINELINE - VACUUM DEGASSED - FINE GRAIN PRACTICE

WE HEREBY CERTIFY THE ABOVE INFORMATION IS CORRECT:

ARCELORMITTAL PLATE LLC
QUALITY ASSURANCE LABORATORY
139 MODENA ROAD
COATESVILLE, PA 19320

Elinore Zaplitny
SUPERVISOR – TEST REPORTING
ELINORE ZAPLITNY

410935

TEST CERTIFICATE

PAGE NO: 02 OF 03
FILE NO: 2822-01-02
MILL ORDER NO: 31350-001
MELT NO: R2452
SLAB NO: 1AC
DATE: 02/09/10

HEAT TREAT CONDITION

MATL OR TEST	HEAT TREAT DESCRIPTION	NOM TEMP	HOLD MINS	COOL MTHD
PL/TEST	HARDEN	1659F	16	W.QUENCH
PL/TEST	TEMPER	1280F	27	AIR COOL

TENSILE PROPERTIES

SLAB NO.	LOC	DIR	YIELD STRENGTH PSI X 100	TENSILE STRENGTH PSI X 100	ELONGATION GAGE LGTH	%
1AC	BOT.	TRANS.	937	1038	2.00"	26.0
1AC	TOP	TRANS.	943	1037	2.00"	26.0

WE HEREBY CERTIFY THE ABOVE
INFORMATION IS CORRECT:

ARCELORMITTAL PLATE LLC
QUALITY ASSURANCE LABORATORY
139 MODENA ROAD
COATESVILLE, PA 19320

Elinore Zaplitny
SUPERVISOR – TEST REPORTING
ELINORE ZAPLITNY

410935

TEST CERTIFICATE

PAGE NO: 03 OF 03
FILE NO: 2822-01-02
MILL ORDER NO: 31350-001
MELT NO: R2452
SLAB NO: 1AC
DATE: 02/09/10

GENERAL INFORMATION

ALL STEEL HAS BEEN MELTED AND MANUFACTURED IN THE U.S.A.
PRODUCED IN ACCORDANCE WITH INSPECTION SYSTEM REQUIREMENTS OF MIL-I-45208A AMEND #1.
MATERIAL HAS BEEN VACUUM DEGASSED AND CALCIUM TREATED FOR SULFIDE SHAPE CONTROL. FINELINE MOD FOR SULPHUR
NO WELD REPAIR PERFORMED BY ARCELORMITTAL PLATE LLC.
THE TEST RESULTS SHOWN IN THIS REPORT ARE THE RESULTS OF TESTING PERFORMED BY OUR ORGANIZATION.
LOW MELTING ALLOYS OR LOW MELTING COMPOUNDS ARE NOT USED IN THE MANUFACTURE OF ARCELORMITTAL PLATE LLC PRODUCTS OTHER THAN AS DEOXIDIZING AGENTS.
MERCURY OR MERCURY COMPOUNDS ARE NOT USED IN THE MANUFACTURE OF ARCELORMITTAL PLATE LLC PRODUCTS.

NDT, VISUAL AND DIMENSIONAL INSPECTION AS REQUIRED BY THE SPECIFICATION WAS SATISFACTORILY PERFORMED.

MATERIAL HAS BEEN SAMPLED, TESTED, AND INSPECTED IN ACCORDANCE WITH THE SPECIFICATION REQUIREMENTS. THE MANUFACTURER HAS MAINTAINED MANUFACTURING PROCEDURES AND PRACTICES WHICH PRODUCE PLATES WHICH MEET THE MINIMUM PROPERTY REQUIREMENTS THROUGHOUT THE PLATE. THE MATERIAL MEETS ALL SPECIFICATION REQUIREMENTS.

RECORDS ARE AVAILABLE COVERING HEAT NUMBER OF THE MATERIAL USED, PROCESSING OF PLATE, DIMENSIONAL CONTROL EMPLOYED AND HEAT TREATMENT.

KNOWINGLY AND WILLFULLY FALSIFYING OR CONCEALING A MATERIAL FACT ON THIS FORM, OR MAKING FALSE, FICTITIOUS OR FRAUDULENT ENTRIES OR REPRESENTATIONS HEREIN, COULD CONSTITUTE A FELONY PUNISHABLE UNDER FEDERAL STATUTES.

CERTIFICATE OF CONFORMANCE - ALL ITEMS FURNISHED IN THE SHIPMENT ARE IN FULL CONFORMANCE WITH ALL P.O. AND SPEC. REQ.; AND THAT THE T.R.'S REPRESENT THE ACTUAL ATTRIBUTES OF THE ITEMS FURNISHED ON THE ORDER, AND THAT THE TEST RESULTS ARE IN FULL CONFORMANCE WITH ALL P.O. & SPEC. REQ. RECORDS TO SUBSTANTIATE THE ABOVE ARE ON FILE IN

OUR PLANT AND WILL BE MAINTAINED FOR A PERIOD OF 7 YRS. FROM THE DATE OF THE SHIPMENT UNLESS FURNISHED TO THE PURCHASER IN ADVANCE OF OR AT TIME OF SHIPMENT. WHEN RECORDS ARE RETAINED BY US, WE AGREE TO FURNISH SAME TO THE PURCHASER AT ANY TIME DURING THE ABOVE PERIOD UPON REQUEST.

HEAT TREAT PROC. NO. MIL-STD-1684D

B/L #03107 JONES MOTOR CO.

WE HEREBY CERTIFY THE ABOVE INFORMATION IS CORRECT:

ARCELORMITTAL PLATE LLC
QUALITY ASSURANCE LABORATORY
139 MODENA ROAD
COATESVILLE, PA 19320

Elinore Zaplitny

SUPERVISOR – TEST REPORTING
ELINORE ZAPLITNY

Form No. 1360 (R 4/09)

ArcelorMittal USA

Ultrasonic (Thickness and Internal Soundness)
Micrometer, Brinell, and Plate Inspection Report

Customer 2822	Mill Order No. 31350	Item 001	Plate Spec. NAVSEA Tech Pub T9074-0-02-H480-TY1	Date 1-15-10
	Customer P.O. No. E257-451	Size .250 X96 X240		Melt & Slab R2452-1AC
N.D.T. Procedure		Mark No.		Assigned No. Lot# 1703

INTERNAL SOUNDNESS

Over ½" Thru 2 ½"
- ☐ Static Test on 24" Centers
- ☐ 100%

Over 2 ½"
- ☐ Grid & 1 Diagonal 24" Centers
- ☐ Static Test on 8"
- ☐ Other

THICKNESS
ULTRASONIC THICKNESS CHECK ON 2' CENTERS STARTING 6" FROM PLATE EDGE, MICROMETER THICKNESS CHECK, THREE EACH SIDE. TWO EACH END, ALL EQUALLY SPACED.

ULTRASONIC		0.5'	2.5'	4.5'	6.5'	8.5'	10.5'	12.5'	14.5'	
	MICROMETER		271 *		265 *					MICROMETER
0.5'		"T"								
2.5'	264 *						263 *			
4.5'										
6.5'										
8.5'										
10.5'	263 *						263 *			
12.5'										
14.5'										
16.5'	262 *						259 *			
18.5'										
20.5'			261 *		259 *					
22.5'										
24.5'										
26.5'										
28.5'										
30.5'										
32.5'										
34.5'										
36.5'										
38.5'										
40.5'										
42.5'										
44.5'										
46.5'										
48.5'										

MICROMETER "T" = Reference Thickness Starting Point MICROMETER

VISUAL	THICKNESS	SOUNDNESS
☑ TOP ☑ BOTTOM ☑ EDGES	Instr. Mfr/Model/No. C6; Plate Gauge ☑ Satis ☐ Unsatis	Instr. Mfr/Model/No.; Crystal (Straight Beam) 2.25 MHz 1" Dia.
Flat ☑ Within 3/4	Min Allow .240 Found .259	☐ Satis. ☐ Unsatis; Couplant:
Camber OK ☑ Within 1/4	Max Allow .271ASG Found .271	Suppl. Sheet Req. ☐ Yes ☑ No
Length 240 5/8, 240 11/16; Width 96 7/16, 96 1/2, 96 1/2	Remarks: OK Per Spec	Inspector (LEVEL I SNT-TC-1A)
Brinell Hardness (1) (2) (AVG)		Inspection Supervisor (LEVEL II SNT-TC-1A)

[B]ronson Technical Products
RECEIVING INSPECTION REPORT

Shipper# BT03107

VENDOR	PO#	INSPECTED BY
Arcelormittal Plate LLC	E257-451,-381 Add#1, ~~451~~ Add#2 F257-65, -118	Dema Hudson
LOCATION	**VIA**	**DATE**
Conshohocken, PA.	Jones Motor Co.	2-9-10

ITEM	SPECIFICATION	QUAN.	SIZE	HEAT/LOT - SLAB	STOCK #	COLOR CODE	COST
1	HY80 TY.1	1	1/4 X 96 X 240	R2452-01AC	410935		
2	EH36T	1	3/8 X 96 X 478	R2651-01DB	310527		
3	HY80 TY.1	1	3/16 X 60 X 240	R2994-01AA	410950		
4		1	3/16 X 60 X 240	R2994-01AJ	410951		
5		1	3/16 X 60 X 240	R2994-01AK	410952		
6		1	3/16 X 60 X 240	R2994-01AL	410953		
7	HSLA80 TY.II	1	3/4 X 96 X 480	R2968-04EA	860845		
8	HSLA80 TY.II	1	5/8 X 96 X 480	R3010-01AA	860242		
9	HY100 TY.II	1	3/4 X 96 X 480	R3547-01CA	460281		
10		1	3/4 X 96 X 480	R3672-39AA	460282		

STOCK

CUSTOMER

S.O. #

COMMENTS

QA DOCUMENTS RECEIVED

47,149#

QA REVIEW BY

QA RELEASE BY | DATE | DMR #

COMMENTS

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Annex E Vendor Cut and Plate Layout Drawings

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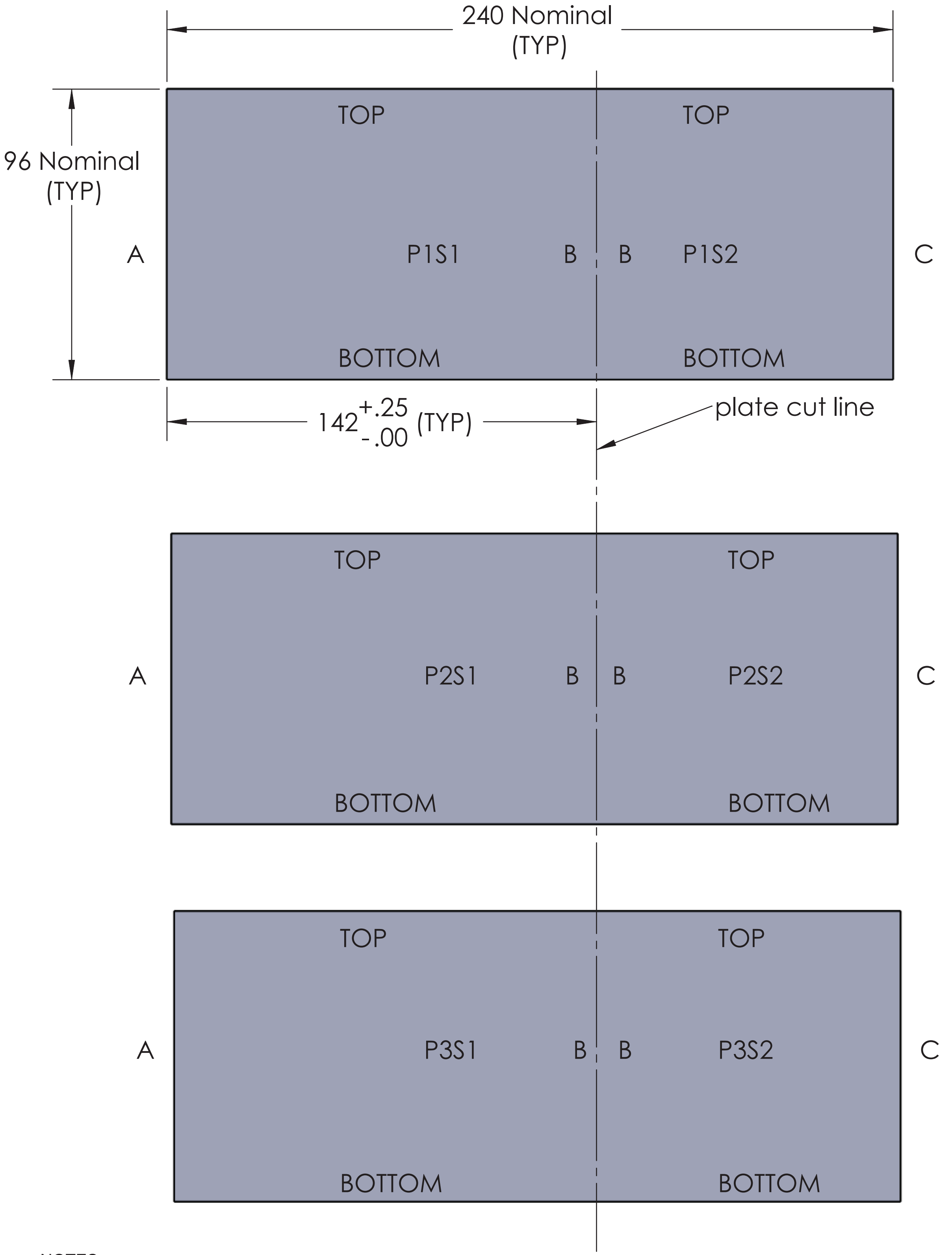


NOTES:
(1) Each plate shall be clearly marked as indicated using a permanent marker or paint pen. No etching, scribing or stamping is permitted.
(2) Markings will be on the same side of both sections for each plate (i.e. P1S1 and P1S2 marked on same side for Plate 1).
(3) Nominal dimensions are for reference only. Plates will **not** be cut by vendor to these dimensions.
(4) Plates will be cut on a burn table and will not be cut by hand or by a hand torch.

COMMENTS:

MATERIAL
HY80

	NAME	DATE
DRAWN	DSS	10Sept21
CHECKED	CMT	10Sept21

DIMENSIONS ARE IN INCHES

TOLERANCES UNLESS OTHERWISE NOTED:

		Tol.	T.I.R.	Finish
1) Decimal:	x.xxx	±0.005"	0.005"	63µinch Ra
	x.xx	±0.015"	0.015"	125µinch Ra
	x.x	±0.030"	0.030"	250µinch Ra
2) Angular:	x.x	± 0.5°		
	x.	±1.0		

C-FER Technologies

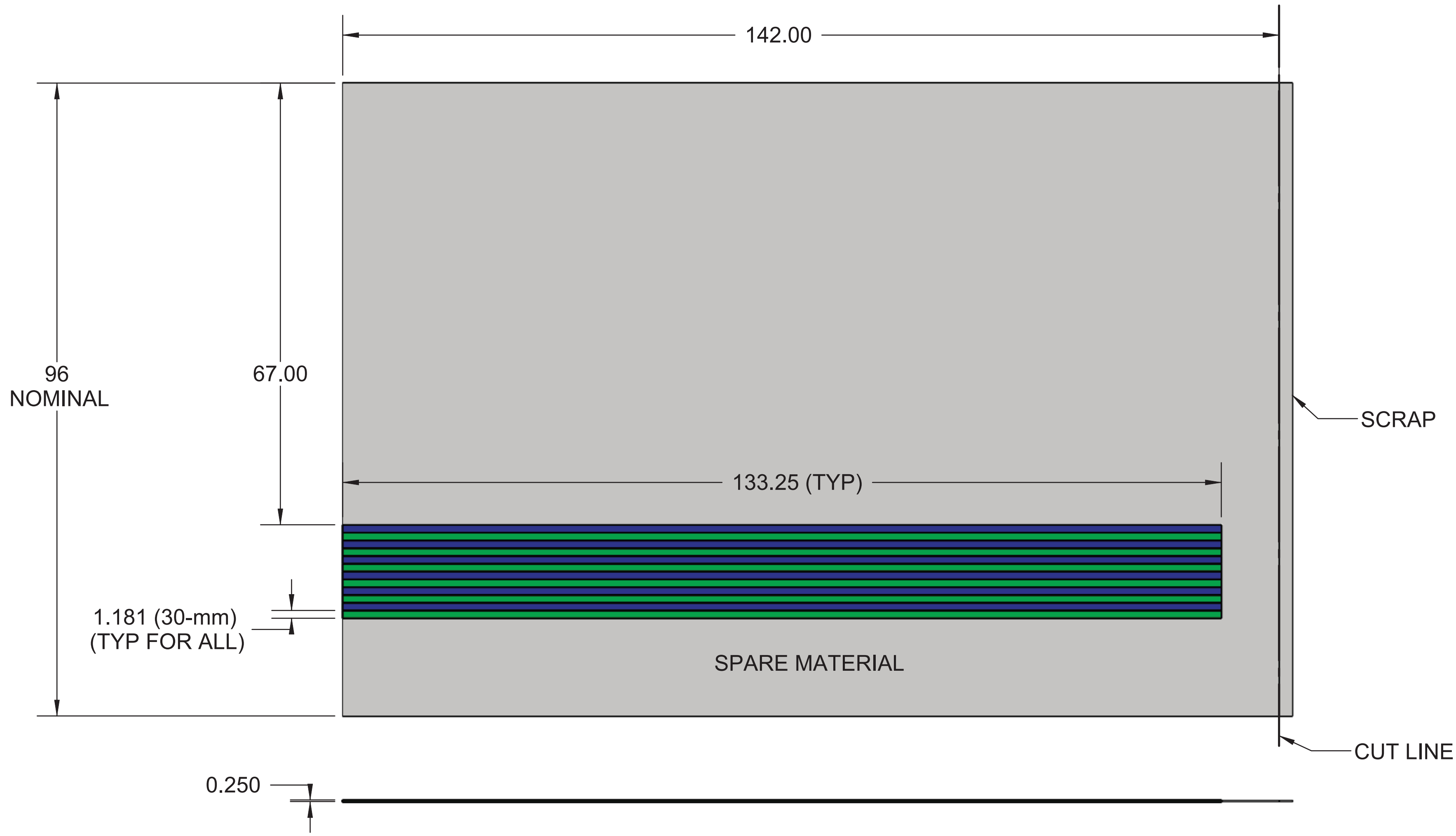
Design & Construction
F034

Vendor Plate Cuts

SIZE	DWG. NO.	REV.
A	CFER-F034-07 119	0

SCALE:1:50 WEIGHT: SHEET 8 OF 12

REV.	DESCRIPTION	DATE	APPROVED
B	RE-ISSUED FOR REVIEW	DSS	Jan 14, 2011



COMMENTS:
Need 12 strips cut.

MATERIAL
HY80

	NAME	DATE
DRAWN	DSS	14Jan11
CHECKED		

DIMENSIONS ARE IN INCHES

TOLERANCES UNLESS OTHERWISE NOTED:

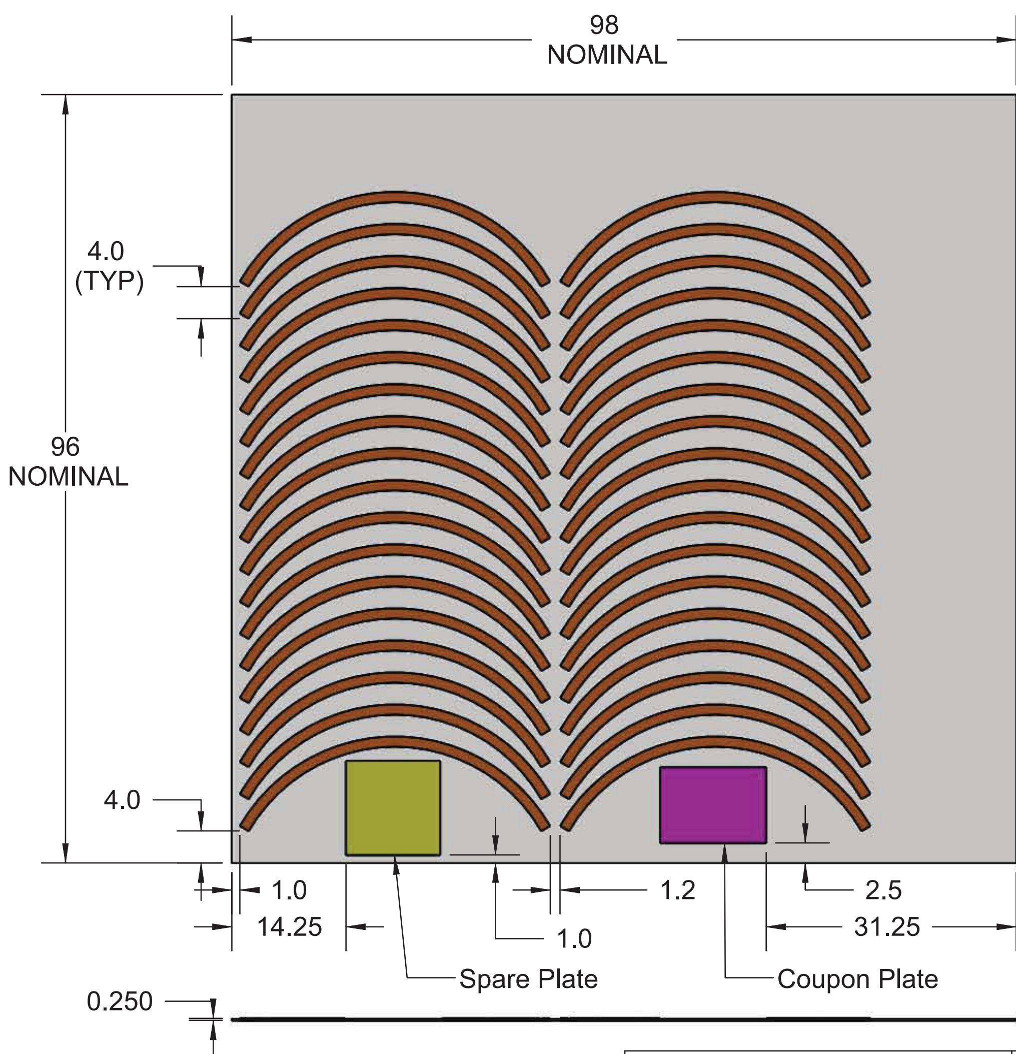
		Tol.	T.I.R.	Finish
1) Decimal:	x.xxx	±0.005"	0.005"	63µinch Ra
	x.xx	±0.015"	0.015"	125µinch Ra
	x.x	±0.030"	0.030"	250µinch Ra
2) Angular:	x.x	± 0.5°		
	x.	±1.0		

C-FER Technologies

Design & Construction
F034
Cylinder Plate Layout

SIZE	DWG. NO.		REV.
A	CFER-F034-PL-01		B
SCALE:1:24	WEIGHT:978.45 Lbs	SHEET 1 OF 4	

REV.	DESCRIPTION	DATE	APPROVED
A	ISSUED FOR REVIEW	DSS	Jan 12, 2011



COMMENTS:
Need 36 curved webs cut.
See CFER-F034-PL-03 for web detail.
See CFER-F034-PL-04 for Spare and Coupon Plate details.

MATERIAL
HY80

	NAME	DATE
DRAWN	DSS	12Jan11
CHECKED	CMT	12Jan11

DIMENSIONS ARE IN INCHES

TOLERANCES UNLESS OTHERWISE NOTED:

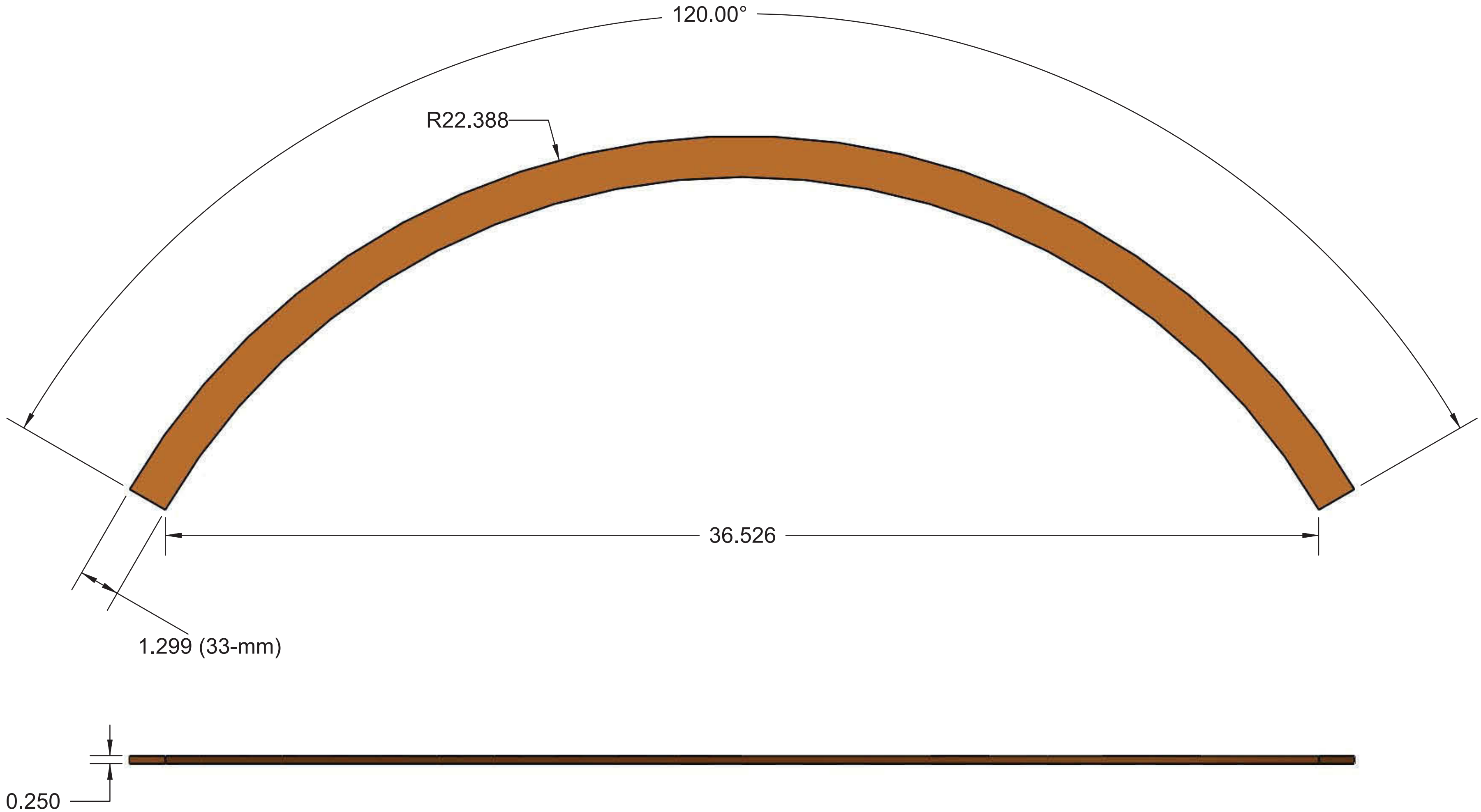
		Tol.	T.I.R.	Finish
1) Decimal:	x.xxx	±0.005"	0.005"	63μinch Ra
	x.xx	±0.015"	0.015"	125μinch Ra
	x.x	±0.030"	0.030"	250μinch Ra
2) Angular:	x.x	± 0.5°		
	x.	±1.0		

C-FER Technologies

Design & Construction
F034
Cylinder Plate Layout

SIZE A | DWG. NO. CFER-F034-PL-02 | REV. A
SCALE:1:24 | WEIGHT:675.91 Lbs | SHEET 2 OF 4

REV.	DESCRIPTION	DATE	APPROVED
A	ISSUED FOR REVIEW	DSS	Jan 12, 2011



COMMENTS:

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MATERIAL
HY80

	NAME	DATE
DRAWN	DSS	12Jan11
CHECKED	CMT	12Jan11

DIMENSIONS ARE IN INCHES

TOLERANCES UNLESS OTHERWISE NOTED:

		Tol.	T.I.R.	Finish
1) Decimal:	x.xxx	±0.005"	0.005"	63µinch Ra
	x.xx	±0.015"	0.015"	125µinch Ra
	x.x	±0.030"	0.030"	250µinch Ra
2) Angular:	x.x	± 0.5°		
	x.	±1.0		

C-FER Technologies

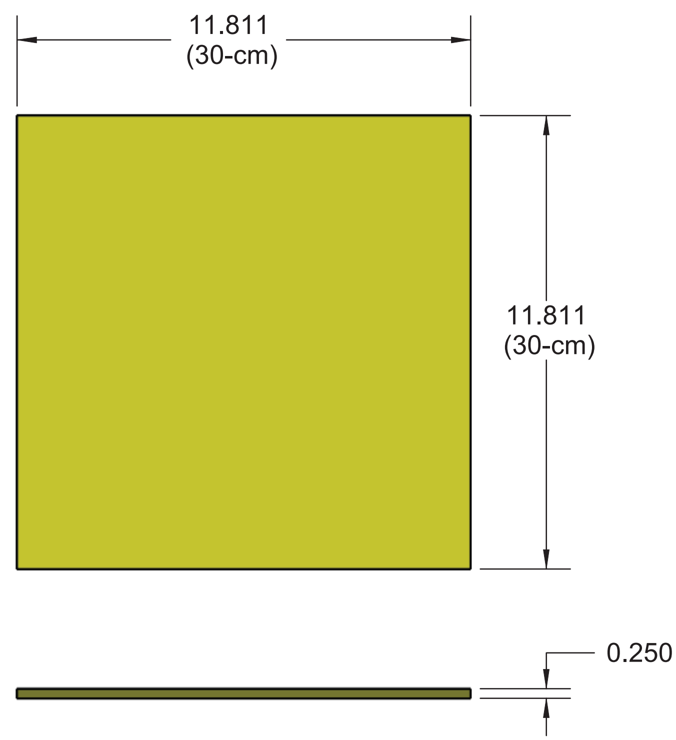
Design & Construction
F034

Cut Web Detail

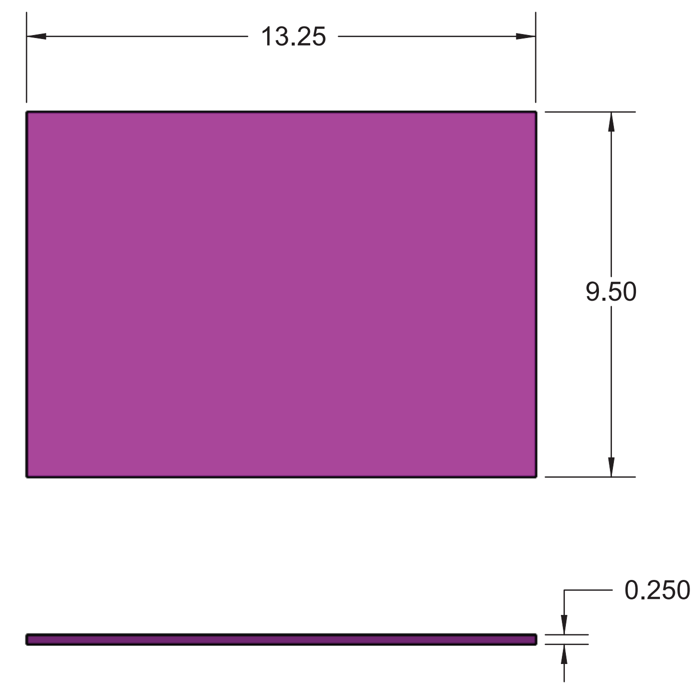
SIZE	DWG. NO.	REV.
A	CFER-F034-PL-03	A

SCALE:1:5 | WEIGHT: | SHEET 3 OF 4

REV.	DESCRIPTION	DATE	APPROVED
A	ISSUED FOR REVIEW	DSS	Jan 12, 2011



SPARE PLATE



COUPON PLATE

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MATERIAL
HY80

	NAME	DATE
DRAWN	DSS	12Jan11
CHECKED	CMT	12Jan11

DIMENSIONS ARE IN INCHES

TOLERANCES UNLESS OTHERWISE NOTED:

		Tol.	T.I.R.	Finish
1) Decimal:	x.xxx	±0.005"	0.005"	63µinch Ra
	x.xx	±0.015"	0.015"	125µinch Ra
	x.x	±0.030"	0.030"	250µinch Ra
2) Angular:	x.x	± 0.5°		
	x.	±1.0		

C-FER Technologies

Design & Construction
F034

Spare and Coupon Plate Detail

SIZE	DWG. NO.	REV.
A	CFER-F034-PL-04	A

SCALE:1:5 | WEIGHT: | SHEET 4 OF 4

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Annex F Fabrication Procedure

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Petersen's Welding

Fabrication Procedure for Collapse Cylinders

The T-framed collapse cylinder shells will be fabricated following the steps listed below. All welding will conform to the enclosed weld procedure specification documents.

1) The HY-80 plate material will be water jet cut following the layout drawings supplied by C-FER Technologies. All material will be tracked accordingly to ensure each collapse cylinder is constructed from a single sheet of material.
2) The water jet parts that require cold forming will be cold rolled to the desired diameters. The collapse cylinder shell and T-frame flanges will be rolled, the seam weld of the parts will then be tacked, and then the parts will be re-rolled to remove any crimping that may occur near the longitudinal seam. In addition to rolling the HY-80 material, two ¾" thick strips of QT100 plate will be cold rolled for a transition ring from the end caps to the collapse cylinder.
3) Three of the arcs that are water jet cut will be tacked together to form the web of each T-frame. The rolled flange will then be tack welded into position on the web of each T-frame. After assembly the butt welds between web pieces will be made. The flange will be stitch weld using 4 mm fillet welds on either side of the flange to web connection. Stitch welding will be used to control distortions. A complete fillet weld will be made on either side of the flange to web connection at completion of welding
4) After three T-frames are fabricated they will be NDE inspected following the requirements in the work scope provided by C-FER.
5) After passing weld inspections the remaining T-frames will be welded and then all T-frames will be measured according to the work scope provided by C-FER.
6) The shell of the collapse cylinder will be tack welded along the seam to provide dimensional stability. The T-frames will be inserted into the ID of the shell and subsequently welded into place. As each T-frame is welded to the shell, the seam weld of the collapse cylinder will be welded between T-frames except for the last cap pass. The last cap pass of the seam weld will be done once the collapse cylinder assembly is complete. The seam weld will be capped from the ID and OD of the collapse cylinder.
7) Grid markings will be placed on the cylinder according to the work scope document provided by C-FER. These grid markings will be protected for the remaining fabrication and transport to C-FER allowing for measurements to be taken at multiple stages of the remaining fabrication.
8) The measurements listed in the scope of work provided by C-FER will be completed.
9) The ends of the collapse cylinder will then be cut and beveled perpendicular to the rolling axis. The end caps will be positioned and tack welded in place.
10) The end caps will then be preheated to 250 F while the collapse cylinder body will remain at 70 F. The end caps will be welded using a full penetration weld with a cap back up.
11) All circumferential welds will be done in a 1G position.
12) Upon return of the first collapse cylinder, the end caps will be torch cut from the collapse cylinder and subsequently prepared by grinding to be welded to the next collapse cylinder. This process will be repeated with the second and third cylinders.

Petersen's Welding

End Cap Fabrication

1) 6" plate material having a minimum yield of 50 ksi will be oxy-fuel torch cut to the rough diameters listed on the drawings.
2) The center cap will be machined to provide sealing surfaces and the desired holes.
3) A bushing will be machined with o-ring grooves and threaded holes to provide a seal surface for the center cap to be attached.
4) After machining the bushing will be inserted into the one end cap that was cut to provide material for the center cap.
5) The bushing will be welded into the end cap by fillet welds on either side of the bushing as marked on the drawings provided by C-FER.
6) Lifting eye holes will be drilled and tapped to facilitate handling of the end caps during fabrication and at C-FER.
7) The opposite end of the collapse cylinder will have a solid 6" thick plate with a minimum yield of 50 ksi will be welded to seal the cylinder.
8) For both end caps the ¾" thick QT100 strip that was cold rolled during cylinder fabrication will be beveled and welded to the end cap as per the drawings supplied by C-FER. The ring will be welded using a full penetration weld to the end cap and then transition to 0.25" thick following a 4:1 transition as per the drawings. This edge will subsequently be welded to the shell of the collapse cylinder.

Simulated Corrosion

1) A simulated corrosion defect will be installed on the desired cylinders by grinding or machining the wall thickness of the collapse cylinder shell to the desired wall loss. The method of metal removal will need to be determined after the collapse cylinder has been welded. This is necessary to determine the deformations that have occurred due to welding. Once the deformations have been quantified the best suited machining method will be determined.
2) After a simulated corrosion defect has been machined a fine grid pattern will be marked across the area to allow for measurements to be taken. Once again the grid lines will be protected to ensure they are present throughout the remaining fabrication.

Weld Buttering

1) Weld buttering will be done by using a short-arc GMAW welding process with ER100S-1 welding consumables. Multiple passes will be placed side by side across the simulated corrosion defect until the thickness of the collapse cylinder shell is greater than the original thickness of the HY-80 plate. The local temperature will be monitored and sufficient time between welding passes will be taken to allow the material to still air cool to within the maximum specified interpass temperature.
2) The weld passes will then be manually blended with a grinder/sander with the original plate material surrounding the simulated repair method.

3) After weld buttering and blending the fine grid pattern will be marked across the area in the original pattern to allow for measurements to be taken. Once again the grid lines will be protected to ensure they are present throughout the remaining fabrication.

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Annex G NDE Report

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Applus RTD

Applus RTD Canada
5504 – 36 Street
Edmonton, Ab. T6B 3P3
T 780 440 6600
F 780 440 2538
www.applusrtd.ca

NDE REPORT # 031711-001

Date (m/d/y): 3/17/11 Page 1 of 1

RTD Job #:

RTD Dep. #:

Client: Randy Petersen

Address:

PO/WO:

Job location: Applus RTD shop

Procedure(s): ASME V Rev. #:

Code(s): ASME VIII

Client Rep.:

Part(s) Examined: (3) Welded T-frame, fillet welds and butt welds

Calibration Standard:

Surface Condition: ☒ Weldment ☐ Ground ☐ Machined ☐ Sandblasted ☐ Painted ☐ Other

Method: ☒ MT ☐ PT ☐ VT ☐ Other

Surface Temp (C°): ☐ < 5 > 5 ☒ < 60 ☒ > 60

Equipment Type	RTD Asset #	Cal. Due Date (m/d/y)	**Test Medium**	**Family**	**Batch #**	**Technique** MPI	LPI
☐ Yoke	7064	03/28/11	☐ Wet Fluorescent			☒ AC	☐ Water Washable
☐ Perm. Magnet			☐ Dry Powder			☐ DC	☐ Post Emulsified
☐ Coil			☒ Wet Magnetic Ink	7HF		☒ Continuous	☐ Solvent Removable
☐ Black Light			☒ Contrast	WCP-2		☐ Residual	☐ Other
☐ Alloy Analyzer			☐ Visible Dye			☐ Other	Dwell Time: min
☐ Hardness Tester			☐ Fluorescent Dye				Develop Time: min
☐ Other			☐ Developer				

Blacklight Intensity ≥ 1000 μW/cm² @ 18" from surface of part: ☐ Accept

Whitelight Intensity ≥ 100 fc @ surface of part: ☒ Accept

INSPECTION DETAILS

Scope: MPI of 3 welded T-frames, fillet welds and butt welds

Results: No evidence of any cracking, acceptable to code.

Assistant 1:

Assistant 2:

☐ CGSB ☐ ASNT ☐ SNT Level: ☐ 1 ☐ 2

Discipline: ☐ UT ☐ MT ☐ PT ☐ ET ☐ RT ☐ VT

Technician: **Peter den Boer**

☐ CGSB ☐ ASNT ☒ SNT Level: ☐ 1 ☒ 2 ☐ 3

Discipline: ☐ UT ☒ MT ☐ PT ☐ ET ☐ RT ☐ VT

Signature: Peter den Boer

Client Name:	Client Signature:		Date:(m/d/y)	3/17/2011

*Results are an interpretation of the inspection method, not a guarantee. Client signature indicates acceptance of report, results and applicable charges.

T094 Rev 4
Mar. 25, 08

White – Client Green – Client Yellow – Office Pink – Invoice Golden Rod - Technician

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Annex H Dimensional Check Measurements

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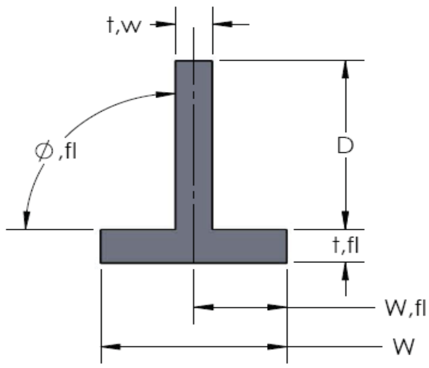
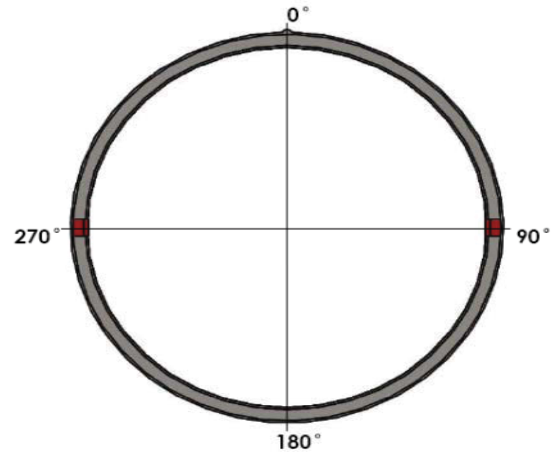
T-FRAME MEASUREMENTS - Post-welding (flange-web)

(to be done following welding but prior to cylinder installation)





Web Depth (D)

	Measurement (Tolerance: L1 = ±2 mm, L2 = ±4 mm)										
	Fr 1	Fr 2	Fr 3	Fr 4	Fr 5	Fr 6	Fr 7	Fr 8	Fr 9	Fr 10	Fr 11
90°	33.70	32.40	33.30	33.50	32.40	33.60	33.60	34.00	32.60	32.20	33.00
270°	33.00	33.00	33.70	33.40	32.90	34.10	33.50	34.10	33.40	33.20	32.80

Web Thickness (t,w)

	Measurement (Mill Cert Average = 6.74 mm, Tolerance: L1 = ±3%, L2 = ±6%)										
	Fr 1	Fr 2	Fr 3	Fr 4	Fr 5	Fr 6	Fr 7	Fr 8	Fr 9	Fr 10	Fr 11
90°	6.89	6.84	6.80	6.75	6.81	6.92	6.93	6.86	6.80	6.76	6.86
270°	6.88	6.80	6.86	6.78	6.95	6.72	6.74	6.84	6.95	6.91	6.90

Flange Width (W)

	Measurement (Tolerance: L1 = ±1 mm, L2 = ±2 mm)										
	Fr 1	Fr 2	Fr 3	Fr 4	Fr 5	Fr 6	Fr 7	Fr 8	Fr 9	Fr 10	Fr 11
90°	29.20	30.60	30.20	30.00	29.80	29.80	30.00	30.00	30.80	30.50	30.20
270°	30.60	29.20	30.20	30.70	29.10	29.40	29.40	30.70	30.30	29.10	29.60

Flange Thickness (t,fl)

	Measurement (Mill Cert Average = 6.74 mm, Tolerance: L1 = ±3%, L2 = ±6%)										
	Fr 1	Fr 2	Fr 3	Fr 4	Fr 5	Fr 6	Fr 7	Fr 8	Fr 9	Fr 10	Fr 11
90°	6.77	6.80	6.76	6.90	6.81	6.81	6.93	6.76	6.82	6.79	6.85
270°	6.72	6.75	6.74	6.75	6.85	6.90	6.76	6.77	6.90	6.75	6.70

Flange Centre (W,fl)

	Measurement (Tolerance: L1 = ±1 mm, L2 = ±2 mm)										
	Fr 1	Fr 2	Fr 3	Fr 4	Fr 5	Fr 6	Fr 7	Fr 8	Fr 9	Fr 10	Fr 11
90°	16.30	15.70	15.65	15.35	15.35	14.75	14.90	14.80	14.15	15.45	16.00
270°	14.95	15.55	15.40	14.20	15.35	14.05	15.90	15.75	14.85	16.40	15.35

Angle between Flange and Web (θ,fl)

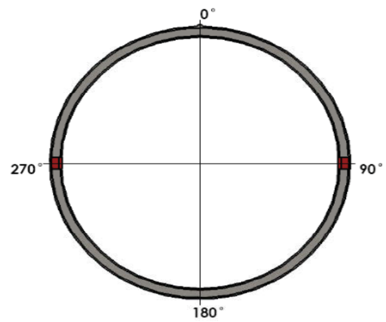
	Measurement (Tolerance: L1 = ±2.5°, L2 = ±5°)										
	Fr 1	Fr 2	Fr 3	Fr 4	Fr 5	Fr 6	Fr 7	Fr 8	Fr 9	Fr 10	Fr 11
90°	89.5	89.8	89.8	87.8	87.3	89.2	88.3	87.9	89.6	89.5	87.8
270°	87.0	88.1	88.2	87.2	87.0	87.9	87.6	88.2	87.2	87.9	89.7

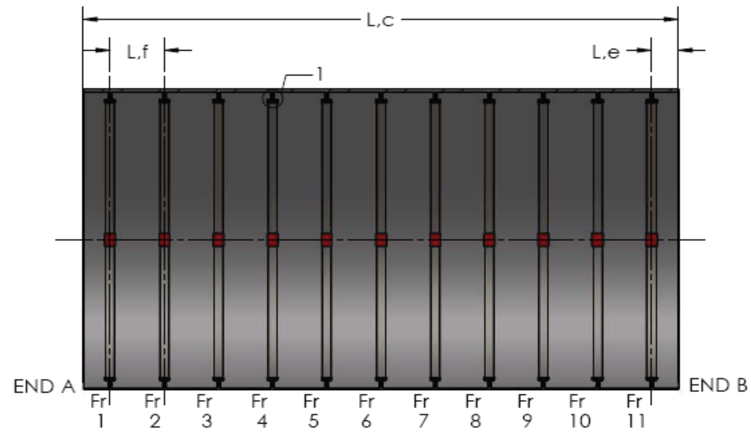
NOTES: (1) Web and Flange thickness measurements are with respect to average values from individual mill certs

Measurements Taken By:	Date:	Title:	C-FER Technologies
Petersen's Welding		**Post-welding (flange-web)**	
Approved By:	Date:	Specimen Identification: **Specimen A - 410930**	Page 1 of 2

CYLINDER MEASUREMENTS

(to be done following cylinder fabrication)





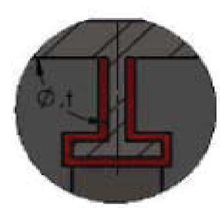
Interframe and End Bay Spacing (L,f & L,e):
(Tolerance: L1 = ±2 mm, L2 = ±4 mm)

	90° (in)	270° (in)
End A to Fr 1	-	-
Fr 1 to Fr 2	159.9	159.4
Fr 2 to Fr 3	161.5	158.5
Fr 3 to Fr 4	159.8	159.2
Fr 4 to Fr 5	159.1	160.8
Fr 5 to Fr 6	160.6	158.7
Fr 6 to Fr 7	158.9	159.9
Fr 7 to Fr 8	160.5	159.6
Fr 8 to Fr 9	158.8	159.8
Fr 9 to Fr 10	160.2	159.3
Fr 10 to Fr 11	158.5	159.8
Fr 11 to End B	-	-

Tilt Angle between Shell and Web (θ,t):
(see Detail 1) (Tolerance: L1 = ±2.5°, L2 = ±5°)

	90° (deg)	270° (deg)
Fr 1	89.3	87.4
Fr 2	89.5	89.5
Fr 3	87.2	89.8
Fr 4	88.9	89.0
Fr 5	89.8	87.6
Fr 6	88.1	89.8
Fr 7	88.5	87.5
Fr 8	87.2	87.7
Fr 9	87.1	87.8
Fr 10	87.7	88.8
Fr 11	88.7	88.8

Cylinder Length (L,c):
90° ________ in
270° ________ in

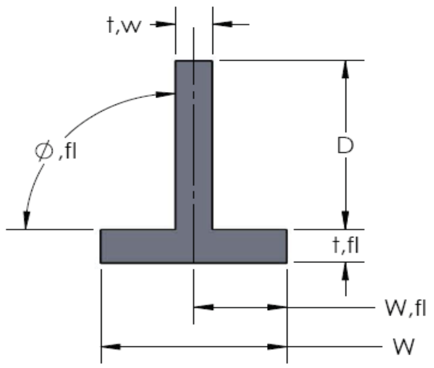


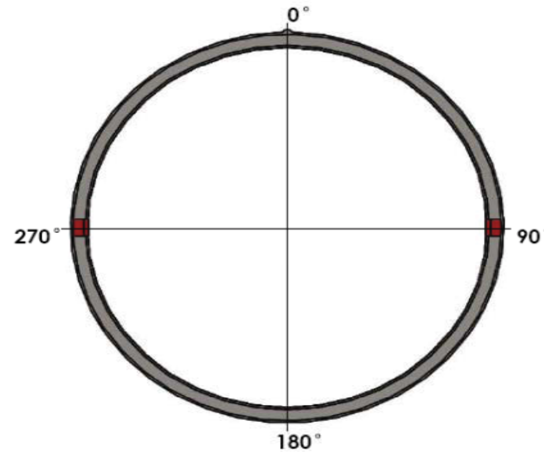
DETAIL 1

Measurements Taken By:	Date:	Title:	
Petersen's Welding		**Post-fabrication Sheet 2**	C-FER Technologies
Approved By:	Date:	Specimen Identification:	
		Specimen A - 410930	Page 2 of 2

T-FRAME MEASUREMENTS - Post-welding (flange-web)

(to be done following welding but prior to cylinder installation)





Web Depth (D)

	Measurement (Tolerance: L1 = ±2 mm, L2 = ±4 mm)										
	Fr 1	Fr 2	Fr 3	Fr 4	Fr 5	Fr 6	Fr 7	Fr 8	Fr 9	Fr 10	Fr 11
90°	33.30	34.10	33.00	33.40	32.10	32.40	33.60	32.70	33.10	32.40	34.10
270°	32.90	32.70	33.50	32.20	32.70	33.40	33.30	32.20	33.20	32.90	33.80

Web Thickness (t,w)

	Measurement (Mill Cert Average = 6.74 mm, Tolerance: L1 = ±3%, L2 = ±6%)										
	Fr 1	Fr 2	Fr 3	Fr 4	Fr 5	Fr 6	Fr 7	Fr 8	Fr 9	Fr 10	Fr 11
90°	6.88	6.80	6.94	6.79	6.89	6.78	6.81	6.88	6.94	6.76	6.83
270°	6.72	6.72	6.74	6.86	6.72	6.71	6.74	6.70	6.95	6.73	6.89

Flange Width (W)

	Measurement (Tolerance: L1 = ±1 mm, L2 = ±2 mm)										
	Fr 1	Fr 2	Fr 3	Fr 4	Fr 5	Fr 6	Fr 7	Fr 8	Fr 9	Fr 10	Fr 11
90°	30.30	29.80	29.80	29.20	30.40	29.00	30.00	29.20	30.40	29.90	30.80
270°	29.70	30.60	30.80	29.80	30.20	29.30	30.30	30.40	29.50	29.00	29.10

Flange Thickness (t,fl)

	Measurement (Mill Cert Average = 6.74 mm, Tolerance: L1 = ±3%, L2 = ±6%)										
	Fr 1	Fr 2	Fr 3	Fr 4	Fr 5	Fr 6	Fr 7	Fr 8	Fr 9	Fr 10	Fr 11
90°	6.85	6.83	6.81	6.91	6.78	6.87	6.89	6.75	6.78	6.78	6.93
270°	6.89	6.86	6.72	6.83	6.74	6.73	6.82	6.82	6.90	6.71	6.85

Flange Centre (W,fl)

	Measurement (Tolerance: L1 = ±1 mm, L2 = ±2 mm)										
	Fr 1	Fr 2	Fr 3	Fr 4	Fr 5	Fr 6	Fr 7	Fr 8	Fr 9	Fr 10	Fr 11
90°	16.30	15.60	16.00	14.85	15.90	15.90	16.10	15.25	14.85	15.45	14.70
270°	15.20	14.55	15.00	16.05	16.15	15.40	14.70	15.25	15.80	15.70	14.85

Angle between Flange and Web (θ,fl)

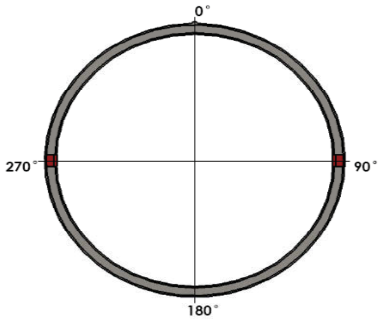
	Measurement (Tolerance: L1 = ±2.5°, L2 = ±5°)										
	Fr 1	Fr 2	Fr 3	Fr 4	Fr 5	Fr 6	Fr 7	Fr 8	Fr 9	Fr 10	Fr 11
90°	89.5	87.7	88.7	87.3	88.6	87.0	88.9	88.8	88.4	87.6	89.3
270°	87.3	87.3	88.1	89.4	89.4	89.4	89.3	88.7	87.4	88.9	87.6

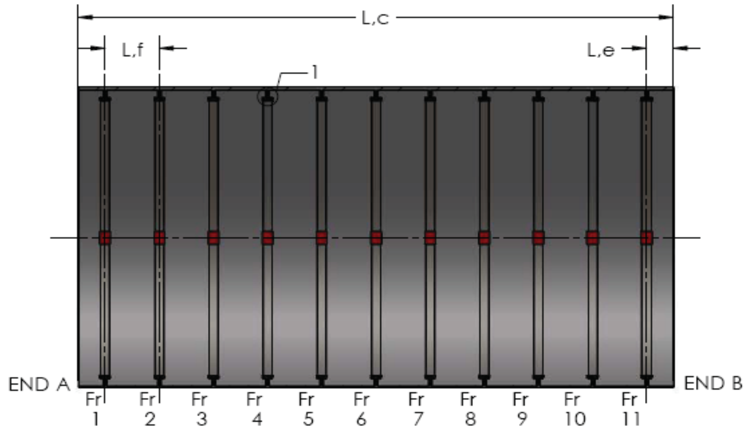
NOTES: (1) Web and Flange thickness measurements are with respect to average values from individual mill certs

Measurements Taken By:	Date:	Title:	C-FER Technologies
Petersen's Welding		**Post-welding (flange-web)**	
Approved By:	Date:	Specimen Identification:	Page 1 of 2
		Specimen B - 411006	

CYLINDER MEASUREMENTS

(to be done following cylinder fabrication)





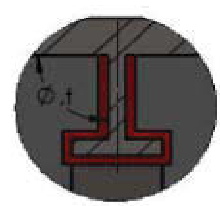
Interframe and End Bay Spacing (L,f & L,e):
(Tolerance: L1 = ±2 mm, L2 = ±4 mm)

	90° (in)	270° (in)
End A to Fr 1	-	-
Fr 1 to Fr 2	161.0	160.6
Fr 2 to Fr 3	160.2	160.5
Fr 3 to Fr 4	158.5	161.3
Fr 4 to Fr 5	161.0	160.5
Fr 5 to Fr 6	159.0	160.6
Fr 6 to Fr 7	159.2	160.5
Fr 7 to Fr 8	158.8	160.5
Fr 8 to Fr 9	159.5	159.2
Fr 9 to Fr 10	158.9	160.2
Fr 10 to Fr 11	159.2	159.9
Fr 11 to End B	-	-

Tilt Angle between Shell and Web (θ,t):
(see Detail 1) (Tolerance: L1 = ±2.5°, L2 = ±5°)

	90° (deg)	270° (deg)
Fr 1	89.4	89.5
Fr 2	88.2	87.9
Fr 3	88.2	87.8
Fr 4	87.2	87.9
Fr 5	87.9	87.8
Fr 6	89.2	88.0
Fr 7	88.0	88.1
Fr 8	88.7	88.6
Fr 9	87.8	89.6
Fr 10	88.5	88.5
Fr 11	87.9	89.8

Cylinder Length (L,c):
90° _________ in
270° _________ in

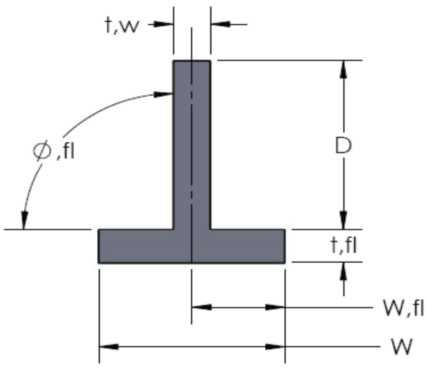


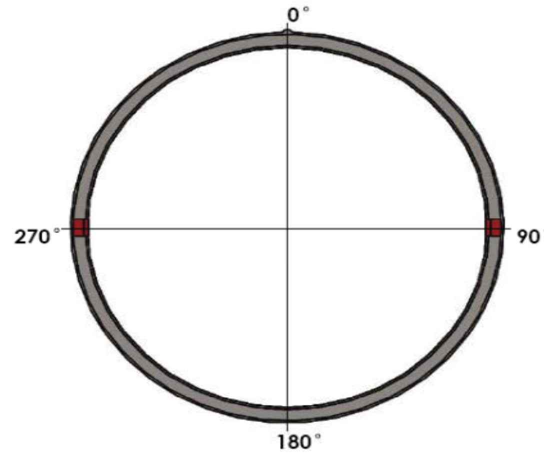
DETAIL 1

Measurements Taken By: **Petersen's Welding**	Date:	Title: **Post-fabrication Sheet 2**	C-FER Technologies
Approved By:	Date:	Specimen Identification: **Specimen B - 411006**	Page 2 of 2

T-FRAME MEASUREMENTS - Post-welding (flange-web)

(to be done following welding but prior to cylinder installation)





Web Depth (D)

	Measurement (Tolerance: L1 = ±2 mm, L2 = ±4 mm)										
	Fr 1	Fr 2	Fr 3	Fr 4	Fr 5	Fr 6	Fr 7	Fr 8	Fr 9	Fr 10	Fr 11
90°	33.60	33.50	33.00	33.80	33.70	33.50	32.80	33.60	33.70	33.00	32.30
270°	33.10	32.20	33.80	33.10	32.40	32.90	32.20	33.90	33.70	33.60	33.30

Web Thickness (t,w)

	Measurement (Mill Cert Average = 6.68 mm, Tolerance: L1 = ±3%, L2 = ±6%)										
	Fr 1	Fr 2	Fr 3	Fr 4	Fr 5	Fr 6	Fr 7	Fr 8	Fr 9	Fr 10	Fr 11
90°	6.86	6.72	6.74	6.83	6.84	6.76	6.81	6.94	6.90	6.70	6.76
270°	6.92	6.84	6.83	6.87	6.72	6.95	6.86	6.81	6.83	6.86	6.79

Flange Width (W)

	Measurement (Tolerance: L1 = ±1 mm, L2 = ±2 mm)										
	Fr 1	Fr 2	Fr 3	Fr 4	Fr 5	Fr 6	Fr 7	Fr 8	Fr 9	Fr 10	Fr 11
90°	30.50	29.60	29.00	29.70	29.70	29.30	29.60	30.10	29.80	29.90	29.90
270°	29.00	29.20	30.70	30.00	30.70	30.50	29.00	30.40	29.20	30.60	29.60

Flange Thickness (t,fl)

	Measurement (Mill Cert Average = 6.68 mm, Tolerance: L1 = ±3%, L2 = ±6%)										
	Fr 1	Fr 2	Fr 3	Fr 4	Fr 5	Fr 6	Fr 7	Fr 8	Fr 9	Fr 10	Fr 11
90°	6.89	6.78	6.83	6.84	6.73	6.85	6.70	6.91	6.79	6.88	6.83
270°	6.72	6.91	6.92	6.83	6.78	6.71	6.82	6.70	6.88	6.90	6.95

Flange Centre (W,fl)

	Measurement (Tolerance: L1 = ±1 mm, L2 = ±2 mm)										
	Fr 1	Fr 2	Fr 3	Fr 4	Fr 5	Fr 6	Fr 7	Fr 8	Fr 9	Fr 10	Fr 11
90°	14.20	15.50	14.20	14.45	14.95	14.60	14.95	14.60	15.70	16.10	15.00
270°	14.55	16.00	15.95	14.40	16.10	14.20	16.15	14.55	15.80	14.35	14.30

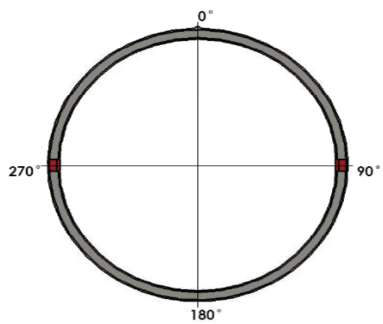
Angle between Flange and Web (θ,fl)

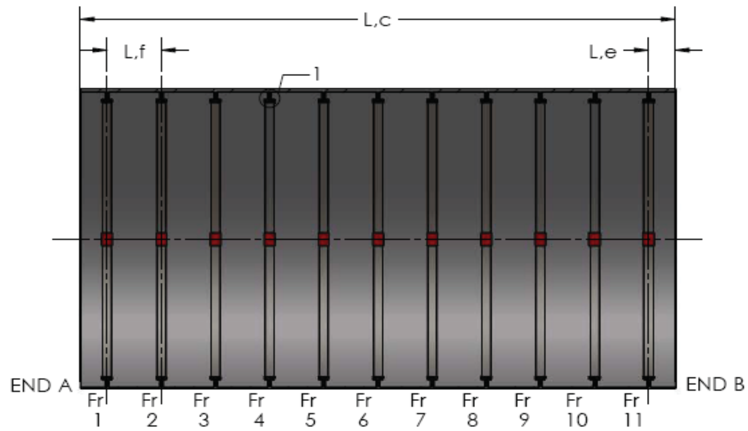
	Measurement (Tolerance: L1 = ±2.5°, L2 = ±5°)										
	Fr 1	Fr 2	Fr 3	Fr 4	Fr 5	Fr 6	Fr 7	Fr 8	Fr 9	Fr 10	Fr 11
90°	88.9	89.6	89.6	89.1	88.8	87.1	88.6	88.5	89.4	87.9	88.6
270°	88.9	87.1	87.4	88.7	88.2	89.9	90.0	88.2	89.2	88.7	87.6

NOTES: (1) Web and Flange thickness measurements are with respect to average values from individual mill certs

Measurements Taken By: **Petersen's Welding**	Date:	Title: **Post-welding (flange-web)**	C-FER Technologies
Approved By:	Date:	Specimen Identification: **Specimen C - 410935**	Page 1 of 2

CYLINDER MEASUREMENTS
(to be done following cylinder fabrication)





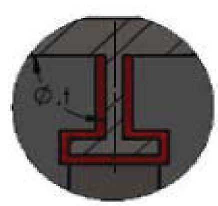
Interframe and End Bay Spacing (L,f & L,e):
(Tolerance: L1 = ±2 mm, L2 = ±4 mm)

	90° (in)	270° (in)
End A to Fr 1	-	-
Fr 1 to Fr 2	160.6	159.6
Fr 2 to Fr 3	160.4	161.1
Fr 3 to Fr 4	161.5	160.7
Fr 4 to Fr 5	159.7	160.2
Fr 5 to Fr 6	158.7	160.5
Fr 6 to Fr 7	160.1	158.8
Fr 7 to Fr 8	160.2	160.1
Fr 8 to Fr 9	161.2	158.8
Fr 9 to Fr 10	160.9	160.0
Fr 10 to Fr 11	160.4	160.5
Fr 11 to End B	-	-

Tilt Angle between Shell and Web (θ,t):
(see Detail 1) (Tolerance: L1 = ±2.5°, L2 = ±5°)

	90° (deg)	270° (deg)
Fr 1	89.8	87.2
Fr 2	88.2	87.3
Fr 3	87.8	89.5
Fr 4	87.7	88.6
Fr 5	87.9	87.2
Fr 6	87.5	89.5
Fr 7	88.2	89.2
Fr 8	88.6	89.5
Fr 9	90.0	88.3
Fr 10	87.2	88.5
Fr 11	88.0	87.5

Cylinder Length (L,c):
90° ________ in
270° ________ in



DETAIL 1

Measurements Taken By: **Petersen's Welding**	Date:	Title: **Post-fabrication Sheet 2**	C-FER Technologies
Approved By:	Date:	Specimen Identification: **Specimen C - 410935**	Page 2 of 2

Annex I Wall Thickness Measurements

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C-FER Technologies

Baseline Model (no corrosion patch <u>or</u> weld buttering)

Welded and no corrosion defects

CIRCUMFERENTIAL LOCATIONS (degrees)	AXIAL LOCATIONS									
	2	**4**	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**
10	6.54	6.50	6.69	6.41	6.47	6.43	6.56	6.44	6.38	6.33
20	6.46	6.51	6.49	6.48	6.39	6.45	6.58	6.57	6.48	6.45
30	6.86	6.83	6.81	6.89	6.79	6.86	6.84	6.83	6.76	6.79
40	6.87	6.77	6.89	6.87	6.78	6.85	6.85	6.89	6.83	6.76
50	6.88	6.82	6.84	6.84	6.78	6.81	6.95	6.93	6.82	6.73
60	6.82	6.82	6.78	6.89	6.83	6.83	6.79	6.77	6.73	6.72
70	6.87	6.86	6.88	6.85	6.81	6.82	6.79	6.76	6.79	6.72
80	6.87	6.87	6.92	6.85	6.84	6.85	6.74	6.87	6.81	6.72
90	6.93	6.89	6.90	6.94	6.82	6.90	6.89	6.97	6.77	6.72
100	6.94	6.96	6.88	6.94	6.83	6.86	6.87	6.83	6.82	6.78
110	6.95	6.92	6.86	6.95	6.79	6.82	6.86	6.77	6.75	6.74
120	6.85	6.85	6.87	6.82	6.80	6.79	6.79	6.77	6.73	6.75
130	6.93	6.88	6.85	6.88	6.79	6.80	6.79	6.82	6.82	6.77
140	6.84	6.83	6.86	6.92	6.80	6.80	6.82	6.79	6.75	6.77
150	6.86	6.85	6.82	6.84	6.82	6.88	6.84	6.83	6.72	6.76
160	6.82	6.87	6.82	6.83	6.82	6.84	6.81	6.75	6.72	6.74
170	6.81	6.85	6.84	6.83	6.74	6.82	6.80	6.93	6.76	6.74
180	6.81	6.87	6.83	6.83	6.73	6.85	6.82	6.75	6.72	6.79
190	6.81	6.79	6.80	6.88	6.89	6.80	6.80	6.79	6.82	6.84
200	6.80	6.82	6.78	6.83	6.82	6.75	6.81	6.81	6.79	6.78
210	6.84	6.82	6.95	6.85	6.78	6.77	6.78	6.80	6.79	6.75
220	6.85	6.86	6.87	6.84	6.75	6.74	6.77	6.77	6.81	6.83
230	6.84	6.84	6.79	6.85	6.85	6.73	6.82	6.81	6.72	6.74
240	6.82	6.84	6.82	6.89	6.81	6.73	6.85	6.81	6.72	6.72
250	6.87	6.83	6.81	6.85	6.79	6.78	6.78	6.79	6.77	6.72
260	6.86	6.86	6.85	6.82	6.68	6.72	6.80	6.78	6.72	6.68
270	6.93	6.85	6.79	6.89	6.37	6.62	6.78	6.75	6.71	6.69
280	6.83	6.86	6.82	6.88	6.50	6.71	6.80	6.77	6.75	6.71
290	6.83	6.78	6.78	6.80	6.49	6.59	6.81	6.80	6.72	6.71
300	6.86	6.81	6.77	6.82	6.52	6.58	6.78	6.72	6.74	6.86
310	6.82	6.79	6.78	6.80	6.43	6.78	6.78	6.80	6.69	6.74
320	6.80	6.80	6.79	6.79	6.42	6.70	6.81	6.90	6.74	6.72
330	6.77	6.74	6.72	6.75	6.53	6.69	6.89	6.82	6.71	6.72
340	6.79	6.79	6.81	6.86	6.75	6.74	6.81	6.80	6.86	6.74
350	6.76	6.79	6.74	6.86	6.79	6.82	6.83	6.78	6.85	6.83
360 (seam weld)	8.54	8.96	7.35	9.25	9.27	9.76	11.20	8.40	10.38	9.01

corrosion patch area (not on this model)

Fine Grid

CUMFERENTIAL	AXIAL LOCATIONS										
	7.5	**8**	**8.5**	**9**	**9.5**	**10**	**10.5**	**11**	**11.5**	**12**	**12.5**
160	6.79	6.77	6.77	Frame 5	6.80	6.83	6.84	Frame 6	6.82	6.85	6.89
165	6.76	6.84	6.79		6.81	6.84	6.80		6.84	6.85	6.88
170	6.82	6.79	6.80		6.79	6.83	6.80		6.81	6.85	6.86
175	6.81	6.78	6.77		6.78	6.82	6.83		6.83	6.86	6.81
180	6.84	6.78	6.78		6.80	6.79	6.85		6.82	6.86	6.84
185	6.84	6.80	6.79		6.81	6.80	6.80		6.81	6.87	6.84
190	6.83	6.83	6.84		6.83	6.82	6.82		6.85	6.87	6.85
195	6.85	6.87	6.85		6.83	6.83	6.83		6.84	6.86	6.87
200	6.84	6.87	6.84		6.84	6.83	6.86		6.87	6.86	6.86

Damaged Model (has corrosion patch but no weld buttering)

Welded and no corrosion defects

CIRCUMFERENTIAL LOCATIONS (degrees)	AXIAL LOCATIONS 2	4	6	8	10	12	14	16	18	20
10	6.76	6.71	6.71	6.76	6.76	6.86	6.83	6.73	6.78	6.78
20	6.71	6.78	6.73	6.73	6.78	6.76	6.81	6.76	6.76	6.78
30	6.68	6.68	6.71	6.76	6.73	6.76	6.81	6.73	6.76	6.78
40	6.68	6.76	6.73	6.71	6.76	6.73	6.73	6.73	6.76	6.73
50	6.63	6.71	6.71	6.71	6.76	6.86	6.81	6.76	6.78	6.78
60	6.68	6.68	6.73	6.73	6.73	6.76	6.76	6.76	6.78	6.76
70	6.68	6.71	6.73	6.76	6.73	6.76	6.78	6.76	6.78	6.76
80	6.73	6.73	6.73	6.73	6.71	6.76	6.76	6.76	6.78	6.76
90	6.63	6.68	6.68	6.71	6.73	6.73	6.76	6.76	6.78	6.76
100	6.68	6.71	6.68	6.71	6.76	6.76	6.73	6.76	6.76	6.81
110	6.65	6.68	6.68	6.73	6.78	6.78	6.76	6.78	6.78	6.81
120	6.65	6.68	6.71	6.73	6.76	6.76	6.78	6.76	6.78	6.76
130	6.68	6.71	6.71	6.73	6.76	6.78	6.76	6.76	6.71	6.76
140	6.68	6.71	6.73	6.76	6.81	6.78	6.78	6.81	6.81	6.78
150	6.71	6.81	6.78	6.76	6.78	6.81	6.81	6.78	6.81	6.78
160	6.65	6.73	6.81	6.73	6.76	6.81	6.76	6.78	6.83	6.81
170	6.68	6.78	6.78	6.78	6.76	6.81	6.78	6.81	6.78	6.78
180	6.73	6.76	6.71	6.73	6.76	6.83	6.81	6.78	6.78	6.78
190	6.65	6.73	6.73	6.73	6.73	6.78	6.81	6.76	6.81	6.78
200	6.68	6.68	6.71	6.73	6.71	6.78	6.76	6.83	6.78	6.76
210	6.65	6.71	6.73	6.68	6.76	6.88	6.73	6.78	6.78	6.83
220	6.68	6.73	6.73	6.76	6.73	6.78	6.73	6.76	6.78	6.81
230	6.68	6.68	6.78	6.78	6.78	6.83	6.83	6.78	6.86	6.78
240	6.68	6.71	6.78	6.81	6.81	6.78	6.78	6.81	6.83	6.83
250	6.68	6.68	6.78	6.83	6.78	6.81	6.81	6.86	6.86	6.81
260	6.76	6.73	6.76	6.73	6.76	6.78	6.76	6.86	6.81	6.81
270	6.73	6.71	6.76	6.73	6.76	6.81	6.78	6.78	6.78	6.81
280	6.68	6.71	6.76	6.83	6.83	6.99	6.81	6.81	6.83	6.81
290	6.71	6.71	6.73	6.76	6.78	6.78	6.83	6.78	6.78	6.76
300	6.71	6.71	6.76	6.76	6.73	6.76	6.73	6.76	6.78	6.73
310	6.73	6.78	6.76	6.78	6.76	6.78	6.73	6.73	6.76	6.81
320	6.81	6.83	6.78	6.78	6.76	6.78	6.76	6.76	6.76	6.86
330	6.76	6.78	6.81	6.73	6.78	6.81	6.73	6.76	6.76	6.76
340	6.78	6.76	6.76	6.76	6.78	6.78	6.76	6.73	6.76	6.73
350	6.76	6.78	6.86	6.81	6.78	6.88	6.81	6.88	6.76	6.76
360 (seam weld)	6.76	8.20	9.50	9.58	8.00	8.05	7.70	9.07	7.04	8.10

corrosion patch area

With Corrosion Patch - Fine Grid

CUMFERENTIAL	AXIAL LOCATIONS 7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5
160	6.80	6.80	6.81	Frame 5	6.82	6.78	6.78	Frame 6	6.78	6.79	6.83
165	6.78	6.77	6.77		6.79	6.75	6.76		6.78	6.79	6.80
170	6.77	6.77	6.80		6.80	6.79	6.76		6.80	6.77	6.81
175	6.79	6.81	6.85		5.67	5.58	5.51		6.81	6.80	6.79
180	6.81	6.83	6.86		5.60	5.39	5.45		6.85	6.80	6.79
185	6.83	6.84	6.89		5.51	5.43	5.39		6.85	6.83	6.82
190	6.83	6.84	6.86		6.86	6.84	6.80		6.83	6.83	6.84
195	6.83	6.84	6.86		6.86	6.84	6.82		6.86	6.82	6.82
200	6.83	6.87	6.85		6.86	6.87	6.81		6.85	6.85	6.79

Repaired Model (has corrosion patch and weld buttering)

Welded and no corrosion defects

CIRCUMFERENTIAL LOCATIONS (degrees)	AXIAL LOCATIONS 2	4	6	8	10	12	14	16	18	20
10	6.63	6.38	6.48	6.58	6.68	6.65	6.71	6.76	6.68	6.65
20	6.63	6.45	6.43	6.48	6.63	6.53	6.38	6.40	6.45	6.45
30	6.65	6.53	6.50	6.45	6.65	6.58	6.45	6.38	6.43	6.53
40	6.58	6.50	6.45	6.55	6.76	6.78	6.68	6.71	6.68	6.58
50	6.55	6.65	6.45	6.63	6.76	6.63	6.38	6.35	6.55	6.48
60	6.55	6.71	6.60	6.68	6.58	6.68	6.31	6.31	6.45	6.60
70	6.60	6.73	6.71	6.58	6.58	6.68	6.43	6.37	6.35	6.68
80	6.65	6.73	6.73	6.65	6.53	6.76	6.73	6.55	6.35	6.73
90	6.60	6.63	6.71	6.55	6.48	6.73	6.60	6.33	6.18	6.63
100	6.50	6.73	6.71	6.58	6.58	6.73	6.58	6.32	6.30	6.68
110	6.45	6.78	6.65	6.50	6.71	6.76	6.65	6.32	6.40	6.65
120	6.35	6.73	6.60	6.40	6.50	6.71	6.63	6.30	6.33	6.53
130	6.50	6.68	6.63	6.45	6.65	6.68	6.68	6.27	6.22	6.53
140	6.58	6.65	6.65	6.60	6.63	6.68	6.63	6.58	6.43	6.40
150	6.68	6.68	6.65	6.65	6.73	6.68	6.65	6.55	6.38	6.40
160	6.68	6.63	6.48	6.68	6.73	6.71	6.60	6.55	6.58	6.35
170	6.71	6.68	6.42	6.68	6.78	6.73	6.53	6.38	6.50	6.48
180	6.65	6.73	6.40	6.71	6.76	6.73	6.55	6.45	6.43	6.63
190	6.48	6.65	6.58	6.68	6.71	6.68	6.55	6.37	6.34	6.68
200	6.53	6.65	6.63	6.68	6.68	6.68	6.65	6.60	6.30	6.65
210	6.43	6.63	6.63	6.68	6.68	6.63	6.78	6.65	6.35	6.63
220	6.53	6.65	6.65	6.73	6.78	6.65	6.63	6.65	6.60	6.40
230	6.55	6.68	6.71	6.76	6.76	6.68	6.65	6.68	6.45	6.28
240	6.68	6.68	6.68	6.71	6.71	6.65	6.73	6.68	6.22	6.23
250	6.58	6.65	6.65	6.68	6.71	6.65	6.68	6.68	6.00	5.95
260	6.45	6.65	6.63	6.68	6.71	6.65	6.71	6.68	5.94	6.04
270	6.45	6.65	6.63	6.68	6.73	6.65	6.68	6.71	5.74	6.02
280	6.38	6.68	6.68	6.68	6.71	6.68	6.68	6.71	6.14	6.12
290	6.58	6.76	6.71	6.71	6.73	6.73	6.71	6.71	6.31	6.32
300	6.58	6.68	6.63	6.63	6.63	6.65	6.60	6.71	6.35	6.35
310	6.68	6.63	6.58	6.68	6.68	6.65	6.68	6.68	6.38	6.43
320	6.65	6.63	6.45	6.65	6.68	6.65	6.65	6.65	6.40	6.48
330	6.65	6.63	6.43	6.71	6.65	6.68	6.63	6.68	6.45	6.48
340	6.68	6.68	6.45	6.71	6.68	6.63	6.63	6.68	6.63	6.45
350	6.71	6.68	6.48	6.68	6.71	6.65	6.63	6.71	6.63	6.50
360 (seam weld)	9.07	9.32	12.45	9.40	10.21	9.78	9.63	9.63	9.78	9.14

corrosion patch area

With Corrosion Patch - Fine Grid

		AXIAL LOCATIONS										
		7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5
C U M F E R E N T I A L	160	6.75	6.70	6.78		6.85	6.71	6.79		6.82	6.72	6.75
	165	6.80	6.75	6.82	F	6.79	6.79	6.73	F	6.79	6.76	6.73
	170	6.79	6.73	6.80	r	6.81	6.81	6.79	r	6.83	6.72	6.76
	175	6.78	6.78	6.84	a	5.47	5.54	5.43	a	6.81	6.77	6.80
	180	6.82	6.77	6.79	m	5.52	5.55	5.46	m	6.82	6.71	6.76
	185	6.82	6.75	6.85	e	5.57	5.55	5.57	e	6.80	6.78	6.74
	190	6.77	6.72	6.74		6.75	6.75	6.76		6.78	6.70	6.75
	195	6.77	6.75	6.78	5	6.75	6.76	6.74	6	6.77	6.76	6.76
	200	6.74	6.65	6.72		6.73	6.72	6.74		6.76	6.66	6.78

With Weld Buttering - Fine Grid

		AXIAL LOCATIONS										
		7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5
C U M F E R E N T I A L	160	6.88	6.84	6.78		6.84	6.80	6.77		6.76	6.74	6.73
	165	6.84	6.83	6.93	F	6.83	6.86	6.77	F	6.80	6.79	6.75
	170	6.80	6.89	6.89	r	6.74	6.83	6.71	r	6.89	6.76	6.78
	175	6.95	6.92	6.75	a	8.36	8.33	7.64	a	6.80	6.79	6.80
	180	6.88	6.80	6.78	m	8.64	8.00	8.30	m	6.79	6.75	6.74
	185	6.98	6.79	6.78	e	7.95	8.05	7.53	e	6.78	6.73	6.74
	190	6.84	6.77	6.73		6.69	6.73	6.67		6.76	6.72	6.70
	195	6.86	6.79	6.79	5	6.79	6.79	6.81	6	6.78	6.73	6.72
	200	6.85	6.81	6.82		6.89	6.87	6.80		6.83	6.73	6.72

Annex J Coupon Test Procedure

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TESTING OF STEEL CYLINDERS

Procedure for Tension Coupon Tests

1. Test Description

1.1 A total of 10 coupons are to be machined from three separate ¼” HY80 plates: six from one plate and two from each of the other plates.

1.2 Coupon tensile test coupons were taken with orientations in the longitudinal and transverse directions.

1.3 Coupons are to be tested at room temperature.

2. Instrumentation and Data Acquisition

2.1. Instrumentation consists of the MTS load cell, the MTS stroke, the MTS hydraulic grips, a strain measurement device (one 2-in. gauge length extensometer for tension coupon tests).

2.2. All data shall be acquired via C-FER’s computer-controlled software and signal conditioning system.

2.3. Computer software shall be set-up to calculate, from the strain measurements, and display the elastic slopes corresponding to values of 195 GPa, 207 GPa and 220 GPa.

2.4. Only equipment that has been calibrated according to C-FER’s established calibration procedure shall be used.

2.5. The following file naming convention will be used for the testing:

- Coupon ID – Test date – Cycle number (ex. P1L1-Mar 24-2)

3. Pretest Measurements, Installation, and Test Set-up

3.1. Mark and measure specimens as shown in the attached measurement sheets.

3.2. Test specimens in C-FER’s 1,000-kN capacity MTS machine.

3.3. Install tension specimens in hydraulic MTS grips.

3.4. Attach strain measurement device as follows:

3.4.1. For the tension tests, attach one 2-in gauge length extensometer to the specimen.

3.4.2. For the tension tests, where Poisson’s Ratio will be measured, attach one 2-in gauge length extensometer and two biaxial strain gauges (spaced 180º apart).

3.5. Set up data acquisition and signal conditioning to record the instruments indicated in Section 2.1.

3.6. Balance and zero instrumentation prior to proceeding with testing.

4. Procedure for Tension Tests

4.1. Set automatic read capability of data acquisition system to take reads at approximately every 100-lb, approximately every 0.001-in of MTS stroke and every 3 seconds.

4.2. Apply a tension load to the specimen at a machine actuator movement rate of approximately **0.009 in/min**. This is to be maintained until the specimen has reached a load of **6,000-lb**, at which point the load will be removed and the extensometer zeroed. This cycle will be repeated one more time. A new data file will be created prior to starting the next cycle (the naming convention listed in Section 2.5 shall be used).

4.3. On the third cycle, apply a tension load to the specimen at a machine actuator movement rate of approximately **0.009 in/min**. This is to be maintained until the specimen has reached its ultimate tensile strength.

4.4. The modulus curves corresponding to values of 195 GPa and 220 GPa will constitute acceptable upper and lower limits of the slope of the stress-strain curve in the elastic region. If the slope of the elastic portion of the stress-strain curve of the test specimen deviates from this range, the test shall be stopped and repeated.

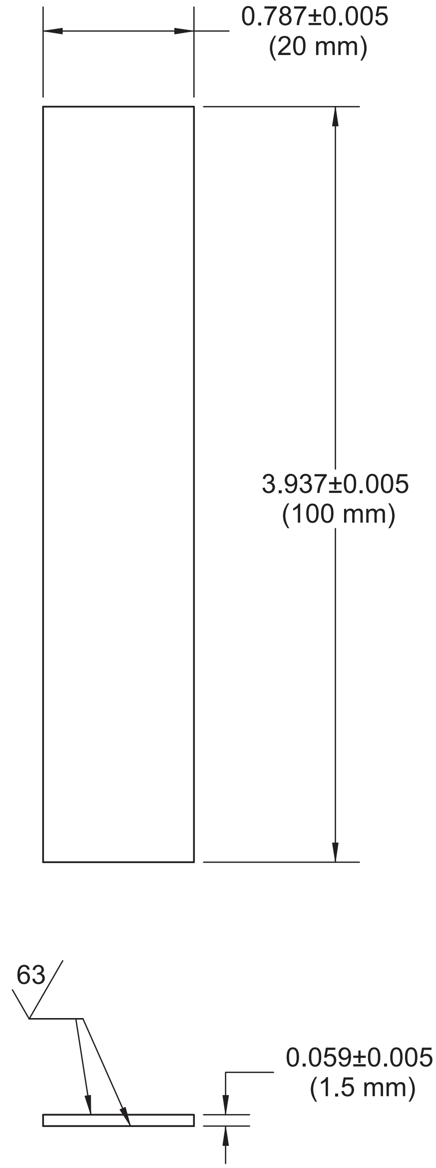
4.5. The extensometer is to be removed from the specimen shortly after achieving the peak load and a drop in the load carrying capacity of the specimen is noticeable. Specimen loading can be briefly paused while removing the extensometer.

4.6. Once the extensometer has been removed, increase the movement rate to **0.09 in/min** and continue specimen loading until complete specimen failure occurs.

4.7. After specimen failure, measure and record total elongation and reduction in area of the fractured specimen.

4.8. Check and backup computer file containing test results.

REV.	DESCRIPTION	DATE	APPROVED
B	ISSUED FOR FABRICATION	Feb 25, 2011	DSS



NOTES:

1. Coupons shall be fabricated in strict accordance with ASTM E1426-98
2. **All** paired surfaces shall be parallel within 0.0005-in/in.
3. **All** surfaces shall be perpendicular to the adjacent surfaces to within 3-ft of arc.
4. Coupons shall be cold cut as close to the final dimensions as possible before machining to minimize curling due to residual stresses.

COMMENTS:

MATERIAL
HY80

	NAME	DATE
DRAWN	DSS	24Feb11
CHECKED		

DIMENSIONS ARE IN INCHES

TOLERANCES UNLESS OTHERWISE NOTED:

		Tol.	T.I.R.	Finish
1) Decimal:	x.xxx	±0.005"	0.005"	63µinch Ra
	x.xx	±0.015"	0.015"	125µinch Ra
	x.x	±0.030"	0.030"	250µinch Ra
2) Angular:	x.x	± 0.5°		
	x.	±1.0		

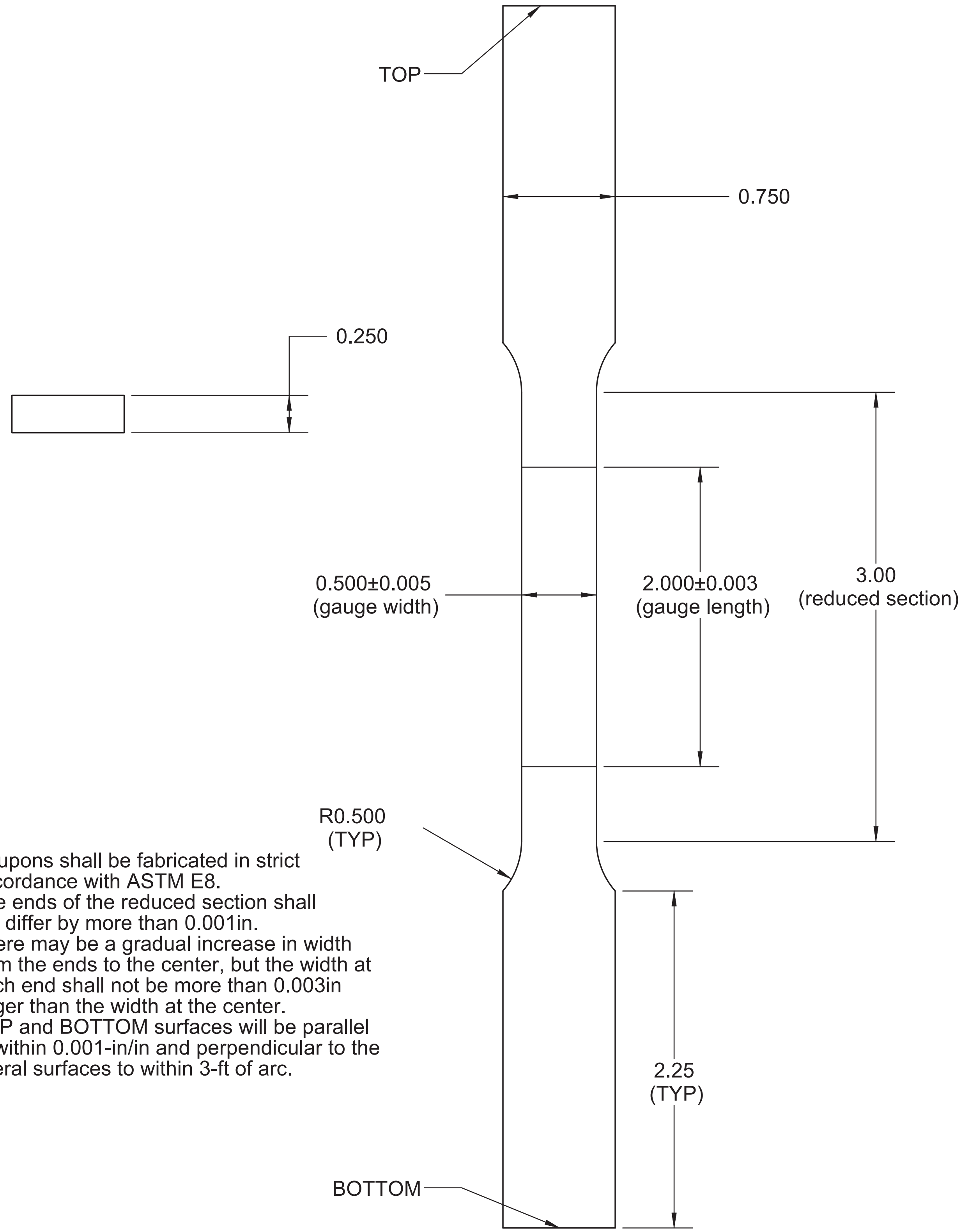
C-FER Technologies

Design & Construction
F034
mXRD Coupon

SIZE	DWG. NO.	REV.
A	CFER-F034-300 153	B

SCALE:1:1 | WEIGHT: | SHEET 1 OF 7

REV.	DESCRIPTION	DATE	APPROVED
B	ISSUED FOR FABRICATION	Feb 25, 2011	DSS



<u>NOTES</u>:

1. Coupons shall be fabricated in strict accordance with ASTM E8.
2. The ends of the reduced section shall not differ by more than 0.001in.
3. There may be a gradual increase in width from the ends to the center, but the width at each end shall not be more than 0.003in larger than the width at the center.
4. TOP and BOTTOM surfaces will be parallel to within 0.001-in/in and perpendicular to the lateral surfaces to within 3-ft of arc.

COMMENTS:

MATERIAL
HY80

	NAME	DATE
DRAWN	DSS	24Feb11
CHECKED		

DIMENSIONS ARE IN INCHES

TOLERANCES UNLESS OTHERWISE NOTED:

		Tol.	T.I.R.	Finish
1) Decimal:	x.xxx	±0.005"	0.005"	63µinch Ra
	x.xx	±0.015"	0.015"	125µinch Ra
	x.x	±0.030"	0.030"	250µinch Ra
2) Angular:	x.x	± 0.5°		
	x.	±1.0		

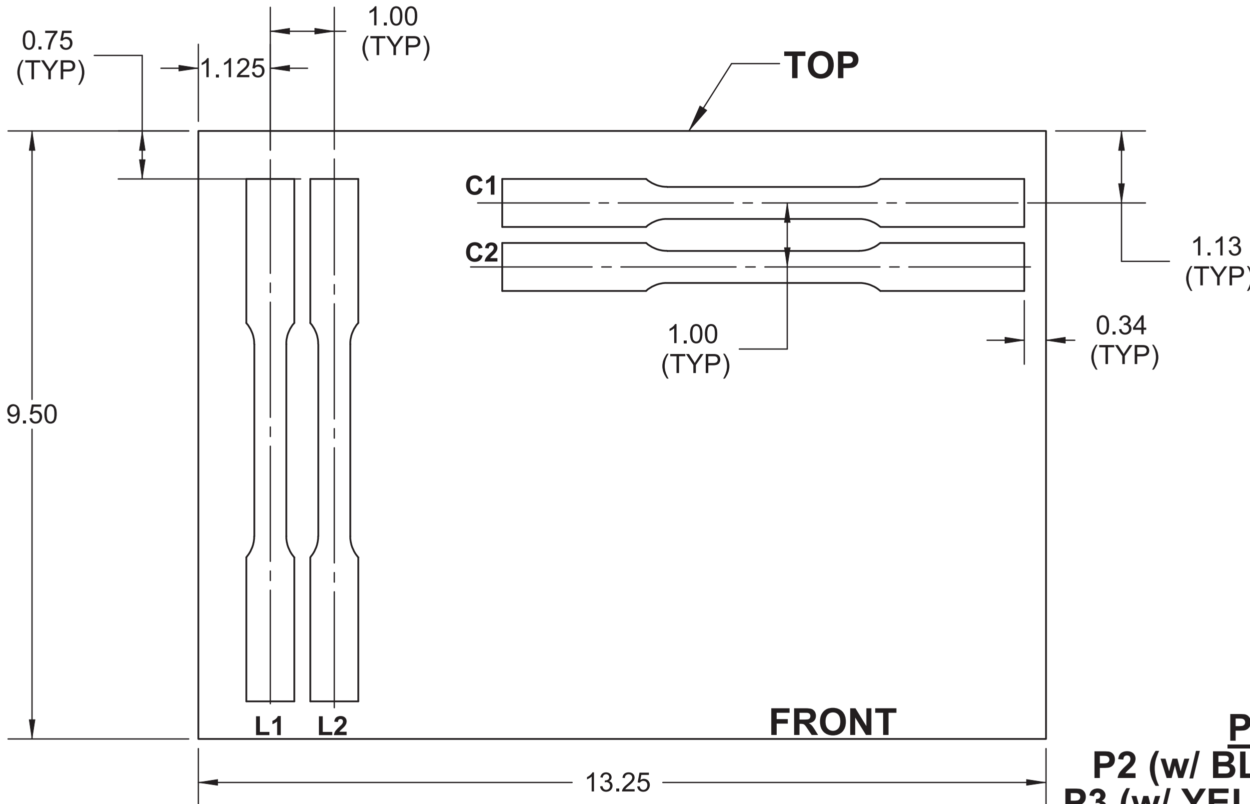
C-FER Technologies

Design & Construction
F034
Coupon Layout

SIZE A | DWG. NO. CFER-F034-301 | REV. B

SCALE:1:1 | WEIGHT: | SHEET 3 OF 7

REV.	DESCRIPTION	DATE	APPROVED
B	ISSUED FOR FABRICATION	Feb 25, 2011	DSS



PANELS
P2 (w/ BLUE paint strip)
P3 (w/ YELLOW paint strip)

NOTES:

1. See drawings CFER-F034-300 and CFER-F034-301 for coupon dimensions.
2. All coupons shall be fabricated using cold cutting techniques (e.g. saw cutting, lathe machining).
3. This extends to the use of cutting and/or machining techniques that would introduce sufficient heat to alter the material properties of the coupons.
4. Coupon Types are indicated in RED. See drawing CFER-F034-304 for a table of corresponding Coupon ID.

COMMENTS:

MATERIAL
HY80

	NAME	DATE
DRAWN	DSS	24Feb11
CHECKED		

DIMENSIONS ARE IN INCHES

TOLERANCES UNLESS OTHERWISE NOTED:

		Tol.	T.I.R.	Finish
1) Decimal:	x.xxx	±0.005"	0.005"	63μinch Ra
	x.xx	±0.015"	0.015"	125μinch Ra
	x.x	±0.030"	0.030"	250μinch Ra
2) Angular:	x.x	± 0.5°		
	x.	±1.0		

C-FER Technologies

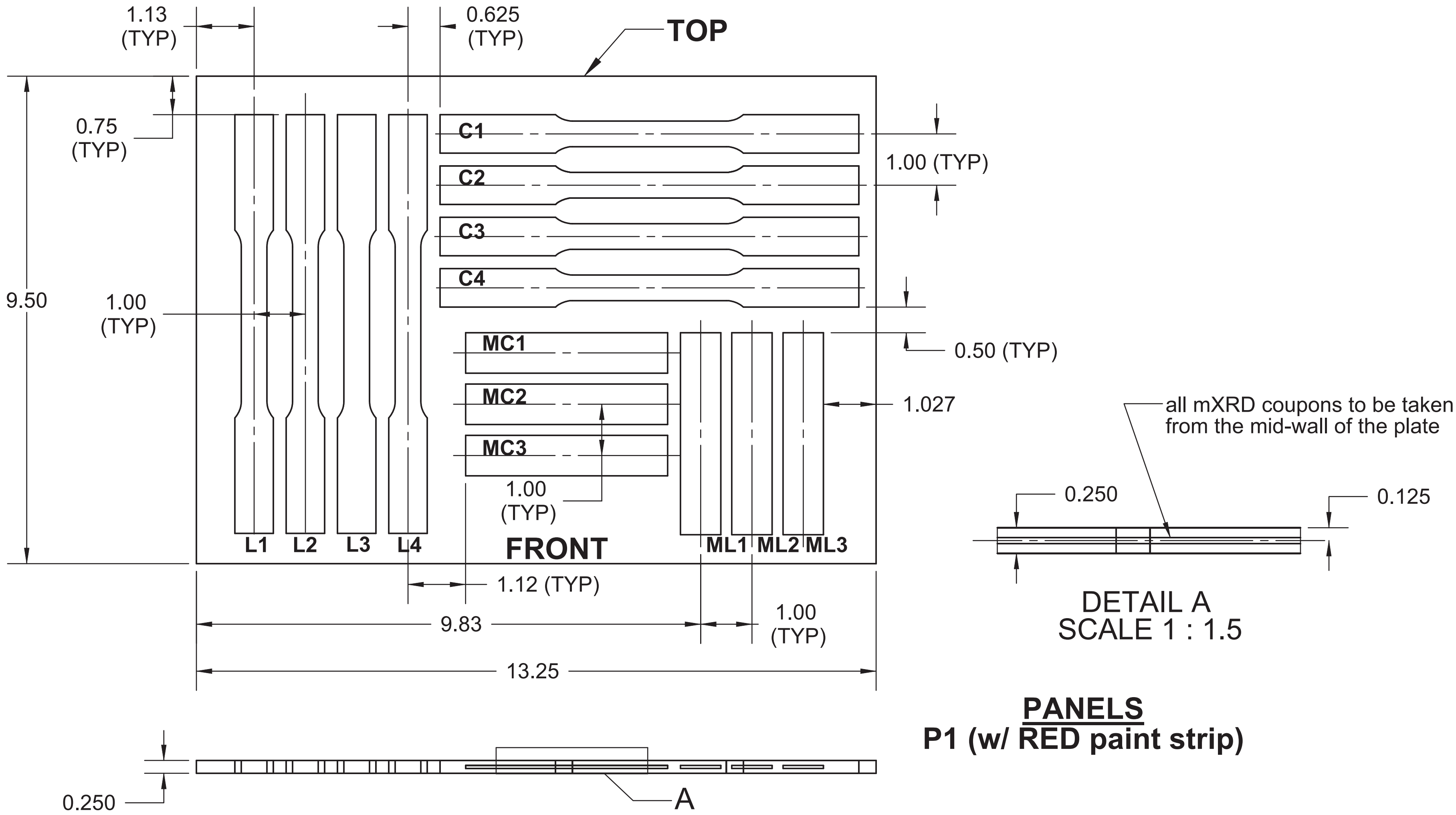
Design & Construction
Templates

Coupon Layout

SIZE A | DWG. NO. CFER-F034-302 | REV. B

SCALE:1:2 | WEIGHT:1.60 Lbs | SHEET 6 OF 7

REV.	DESCRIPTION	DATE	APPROVED
B	ISSUED FOR FABRICATION	Feb 25, 2011	DSS



PANELS

P1 (w/ RED paint strip)

NOTES:

1. See drawings CFER-F034-300 and CFER-F034-301 for coupon dimensions.
2. All coupons shall be fabricated using cold cutting techniques (e.g. saw cutting, lathe machining). This extends to the use of cutting and/or machining techniques that would introduce sufficient heat to alter the material properties of the coupons.
3. Coupon Types are indicated in RED. See drawing CFER-F034-304 for a table of corresponding Coupon ID.

COMMENTS:

MATERIAL
HY80

	NAME	DATE
DRAWN	DSS	24Feb11
CHECKED		

DIMENSIONS ARE IN INCHES

TOLERANCES UNLESS OTHERWISE NOTED:

		Tol.	T.I.R.	Finish
1) Decimal:	x.xxx	±0.005"	0.005"	63µinch Ra
	x.xx	±0.015"	0.015"	125µinch Ra
	x.x	±0.030"	0.030"	250µinch Ra
2) Angular:	x.x	± 0.5°		
	x.	±1.0		

C-FER Technologies

Design & Construction Templates

Coupon Layout

SIZE	DWG. NO.	REV.
A	CFER-F034-303	B

SCALE:1:2 | WEIGHT:1.60 Lbs | SHEET 5 OF 7

REV.	DESCRIPTION	DATE	APPROVED
B	ISSUED FOR FABRICATION	Feb 25, 2011	DSS

PANEL		COUPON	
ID	**TYPE**	**TYPE**	**ID**
P1	16 Coupons	L1	P1L1
		L2	P1L2
		L3	P1L3
		L4	P1L4
		C1	P1C1
		C2	P1C2
		C3	P1C3
		C4	P1C4
		ML1	P1ML1
		ML2	P1ML1
		ML3	P1ML3
		ML4	P1ML4
		MC1	P1MC1
		MC2	P1MC2
		MC3	P1MC3
		MC4	P1MC4
P2	4 Coupons	L1	P2L1
		L2	P2L2
		C1	P2C1
		C2	P2C2
P3	4 Coupons	L1	P3L1
		L2	P3L2
		C1	P3C1
		C2	P3C2

NOTES:

1. All coupons shall be identified using the corresponding coupon ID following fabrication (i.e. P1L1, P1MC4, etc.).
2. "L" and "C" series coupons may have the Coupon ID scribed or marked on the tab section only.
3. "ML" or "MC" series coupons **may not** be marked on any surface. They will be placed in individually labeled plastic bags or plastic wrap after fabrication.

COMMENTS:

MATERIAL
HY80

	NAME	DATE
DRAWN	DSS	24Feb11
CHECKED		

DIMENSIONS ARE IN INCHES

TOLERANCES UNLESS OTHERWISE NOTED:

		Tol.	T.I.R.	Finish
1) Decimal:	x.xxx	±0.005"	0.005"	63µinch Ra
	x.xx	±0.015"	0.015"	125µinch Ra
	x.x	±0.030"	0.030"	250µinch Ra
2) Angular:	x.x	± 0.5°		
	x.	±1.0		

C-FER Technologies

Design & Construction
F034

Coupon Identification

SIZE A | DWG. NO. CFER-F034-304 157 | REV. B

SCALE:1:1 | WEIGHT: | SHEET 7 OF 7

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Annex K Coupon Test Reports

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Coupon Test Report

Coupon Identification

C-FER Project Number:	F034
Coupon Number:	P1C2
Cylinder:	Model A
Coupon Type:	Strip
Test Type:	Tension
Orientation (w.r.t. cylinder):	Hoop

Initial Measurements

Initial Width:	12.87 mm
Initial Thickness:	6.75 mm
Extensometer Gauge Length:	50.8 mm
Initial Marked Gauge Length:	50.91 mm
Coupon initial Area:	86.9 mm^2

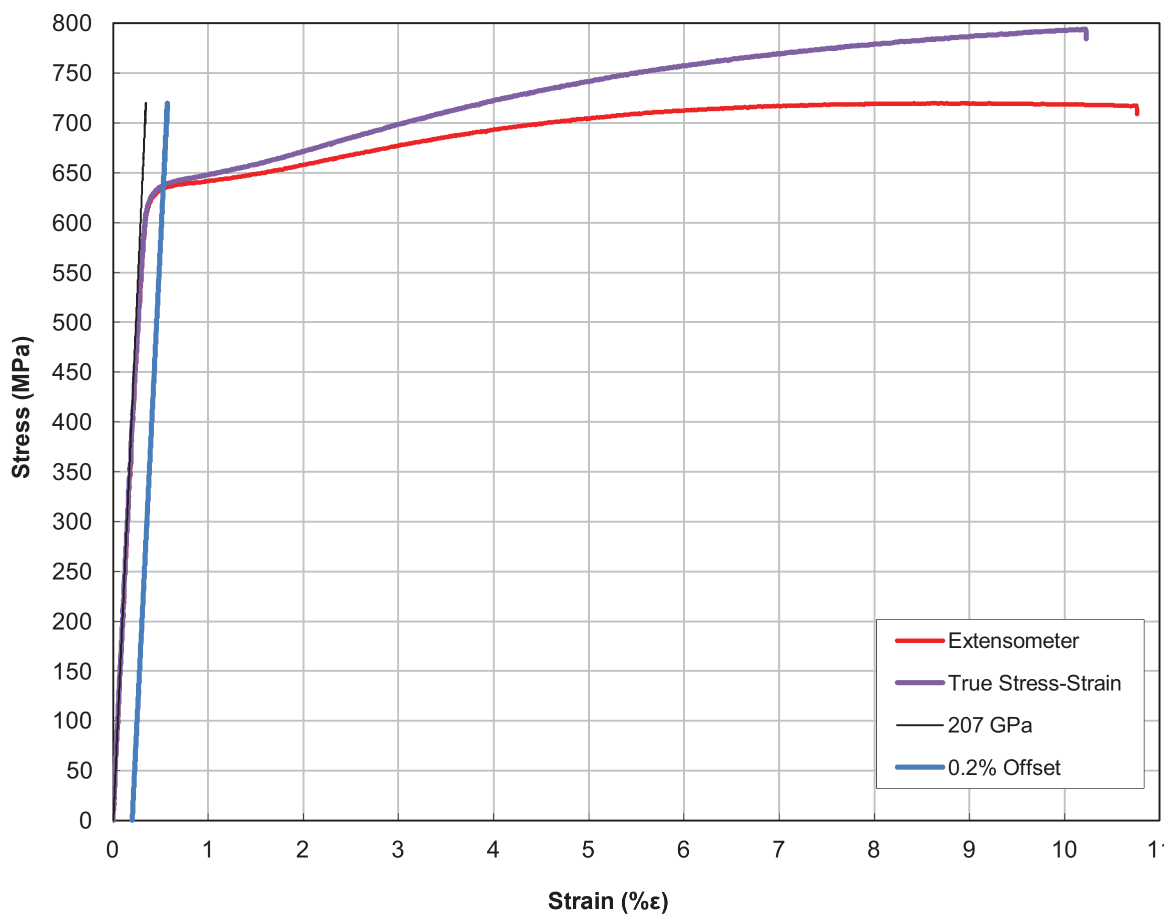
Final Measurements

Final Width:	3.95 mm
Final Thickness:	7.94 mm
Final Marked Gauge Length:	63.09 mm
Coupon Final Area:	31.4 mm^2

Results Summary

Test Date:	25-Mar-11
Young's Modulus, run #1:	194 GPa
Young's Modulus, run #2:	195 GPa
Young's Modulus, run #3:	194 GPa
Young's Modulus, E, ave.:	194 GPa
Yield Strength (@ 0.2% offset):	634 MPa
Ultimate Strength:	720 MPa
Strain at Ultimate:	8.6 %
Elongation:	23.9 %
Area Reduction:	64 %

Comments:



Coupon Test Report

C-FER Technologies

Coupon Identification

C-FER Project Number:	F034
Coupon Number:	P1C3
Cylinder:	Model A
Coupon Type:	Strip
Test Type:	Tension
Orientation (w.r.t. cylinder):	Hoop

Final Measurements

Final Width:	3.14 mm
Final Thickness:	8.14 mm
Final Marked Gauge Length:	63.12 mm
Coupon Final Area:	25.6 mm^2

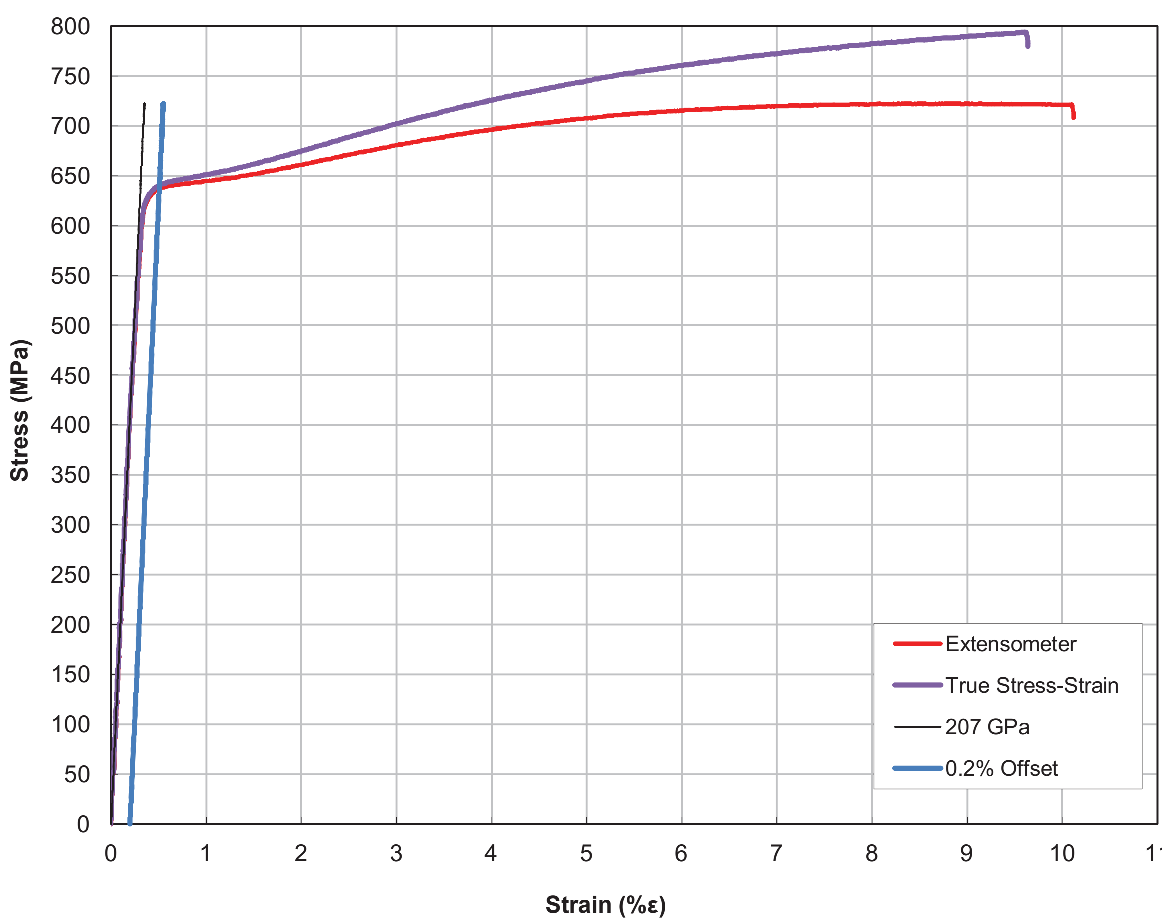
Initial Measurements

Initial Width:	12.87 mm
Initial Thickness:	6.75 mm
Extensometer Gauge Length:	50.8 mm
Initial Marked Gauge Length:	51.01 mm
Coupon initial Area:	86.8 mm^2

Results Summary

Test Date:	26-Mar-11
Young's Modulus, run #1:	200 GPa
Young's Modulus, run #2:	205 GPa
Young's Modulus, run #3:	208 GPa
Young's Modulus, E, ave.:	204 GPa
Yield Strength (@ 0.2% offset):	637 MPa
Ultimate Strength:	722 MPa
Strain at Ultimate:	8.6 %
Elongation:	23.7 %
Area Reduction:	71 %

Comments:



C-FER Technologies

Coupon Test Report

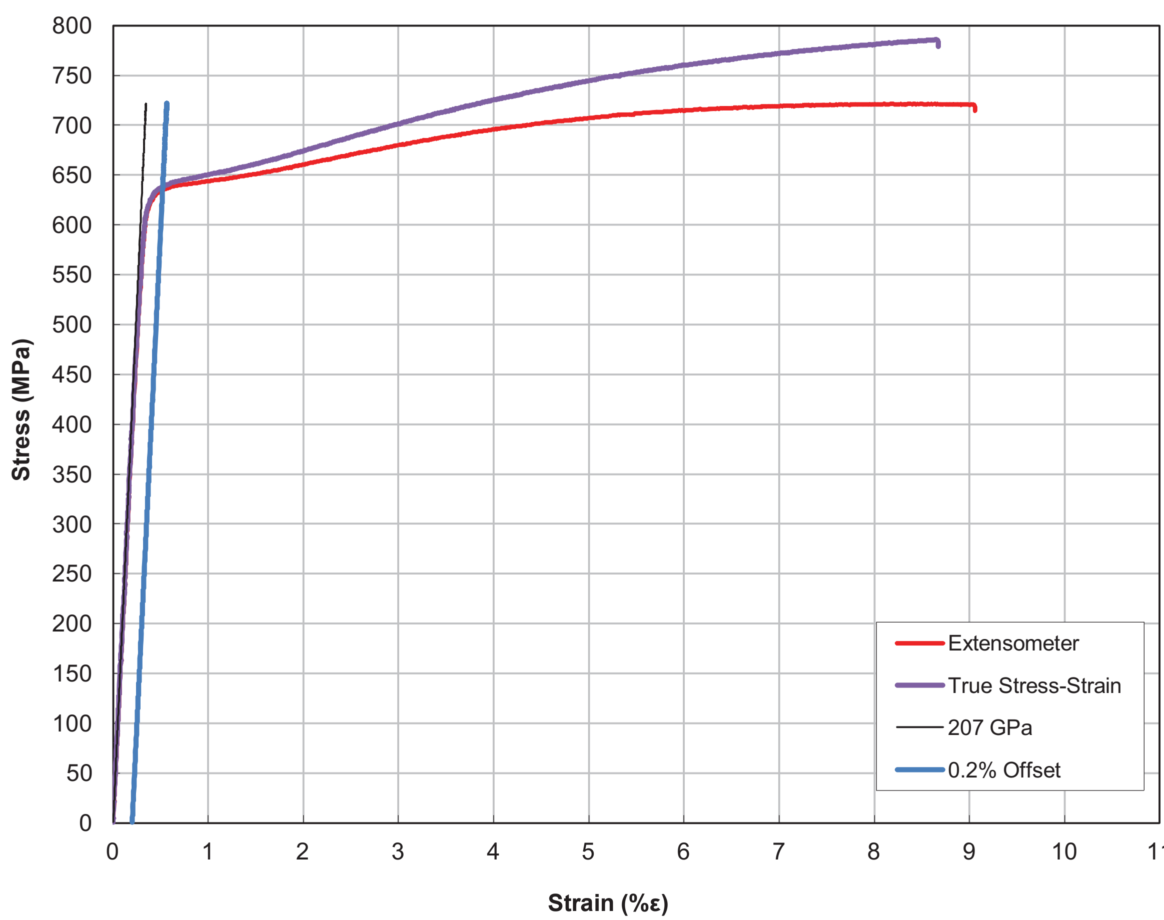
Coupon Identification	
C-FER Project Number:	F034
Coupon Number:	P1C2
Cylinder:	Model A
Coupon Type:	Strip
Test Type:	Tension
Orientation (w.r.t. cylinder):	Hoop

Initial Measurements		
Initial Width:	12.87	mm
Initial Thickness:	6.75	mm
Extensometer Gauge Length:	50.8	mm
Initial Marked Gauge Length:	50.91	mm
Coupon initial Area:	86.9	mm^2

Final Measurements		
Final Width:	3.95	mm
Final Thickness:	7.94	mm
Final Marked Gauge Length:	63.09	mm
Coupon Final Area:	31.4	mm^2

Results Summary		
Test Date:	30-Mar-11	
Young's Modulus, run #1:	198	GPa
Young's Modulus, run #2:	199	GPa
Young's Modulus, run #3:	197	GPa
Young's Modulus, E, ave.:	198	GPa
Yield Strength (@ 0.2% offset):	635	MPa
Ultimate Strength:	721	MPa
Strain at Ultimate:	8.2	%
Elongation:	23.9	%
Area Reduction:	64	%

Comments:



Coupon Test Report

C-FER Technologies

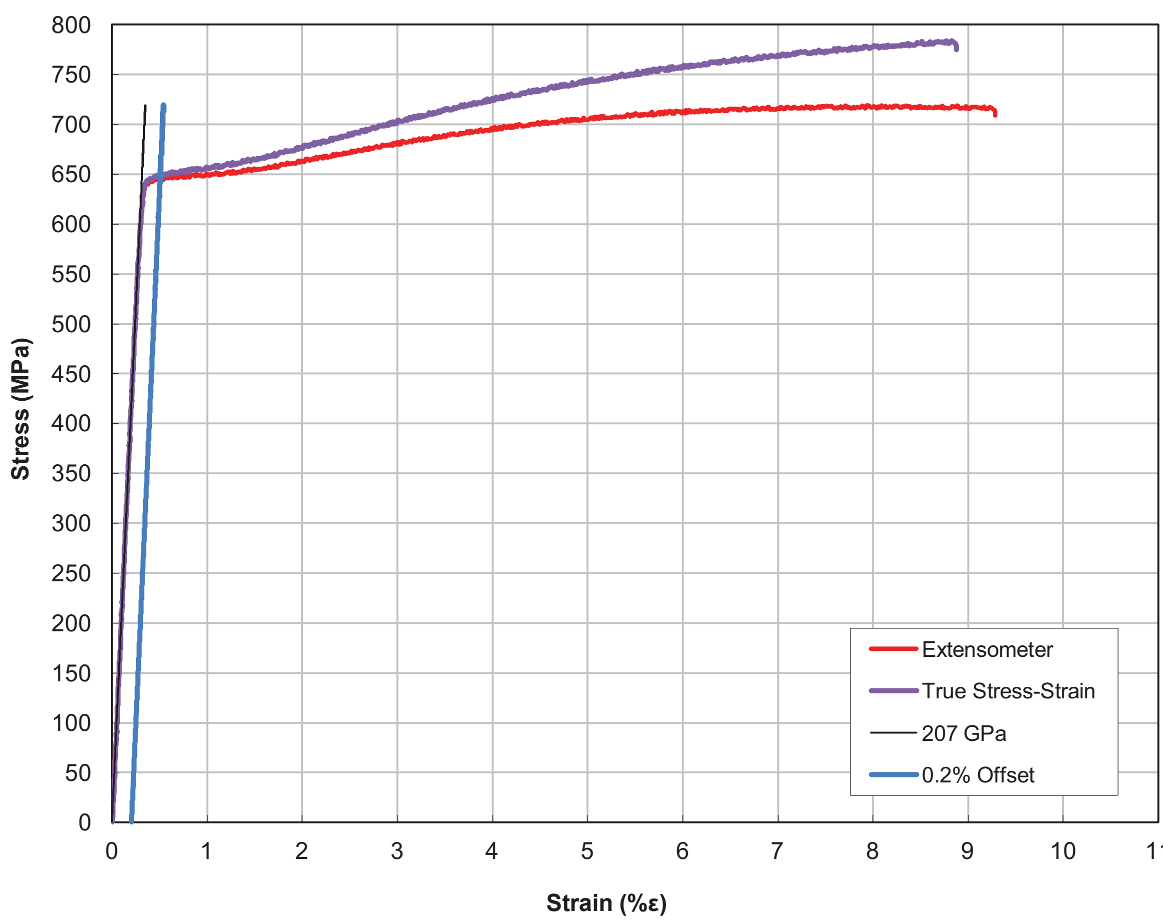
Coupon Identification	
C-FER Project Number:	F034
Coupon Number:	P1L1
Cylinder:	Model A
Coupon Type:	Strip
Test Type:	Tension
Orientation (w.r.t. cylinder):	Longitudinal

Initial Measurements		
Initial Width:	12.86	mm
Initial Thickness:	6.74	mm
Extensometer Gauge Length:	50.8	mm
Initial Marked Gauge Length:	51.11	mm
Coupon initial Area:	86.7	mm^2

Final Measurements		
Final Width:	3.35	mm
Final Thickness:	8.05	mm
Final Marked Gauge Length:	62.10	mm
Coupon Final Area:	27.0	mm^2

Results Summary		
Test Date:	26-Mar-11	
Young's Modulus, run #1:	208	GPa
Young's Modulus, run #2:	208	GPa
Young's Modulus, run #3:	212	GPa
Young's Modulus, E, ave.:	209	GPa
Yield Strength (@ 0.2% offset):	644	MPa
Ultimate Strength:	719	MPa
Strain at Ultimate:	7.9	%
Elongation:	21.5	%
Area Reduction:	69	%

Comments:



C-FER Technologies

Coupon Test Report

Coupon Identification

C-FER Project Number:	F034
Coupon Number:	P1L2
Cylinder:	Model A
Coupon Type:	Strip
Test Type:	Tension
Orientation (w.r.t. cylinder):	Longitudinal

Initial Measurements

Initial Width:	12.79 mm
Initial Thickness:	6.78 mm
Extensometer Gauge Length:	50.8 mm
Initial Marked Gauge Length:	51.21 mm
Coupon initial Area:	86.6 mm^2

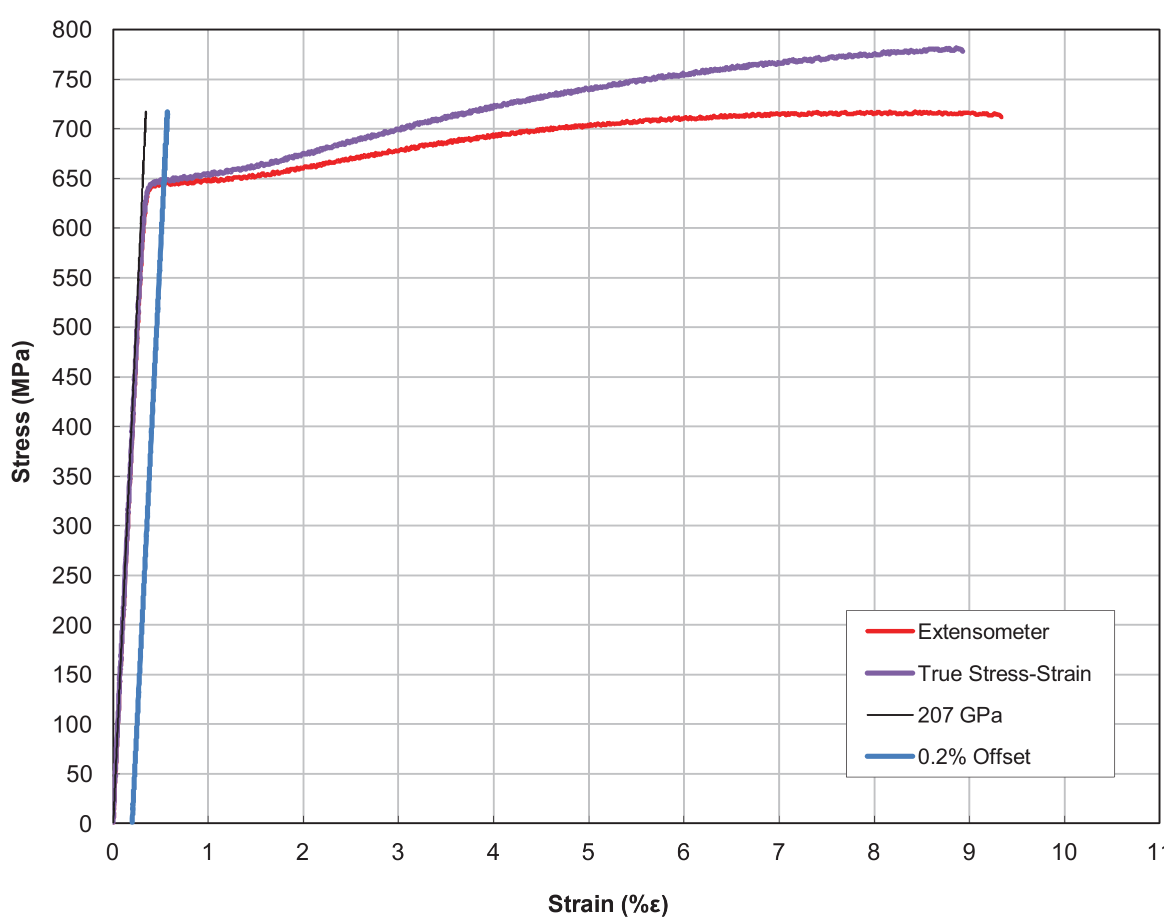
Final Measurements

Final Width:	3.47 mm
Final Thickness:	8.27 mm
Final Marked Gauge Length:	62.13 mm
Coupon Final Area:	28.7 mm^2

Results Summary

Test Date:	26-Mar-11
Young's Modulus, run #1:	201 GPa
Young's Modulus, run #2:	196 GPa
Young's Modulus, run #3:	195 GPa
Young's Modulus, E, ave.:	197 GPa
Yield Strength (@ 0.2% offset):	645 MPa
Ultimate Strength:	717 MPa
Strain at Ultimate:	8.4 %
Elongation:	21.3 %
Area Reduction:	67 %

Comments:



Coupon Test Report

Coupon Identification

C-FER Project Number:	F034
Coupon Number:	P1L3
Cylinder:	Model A
Coupon Type:	Strip
Test Type:	Tension
Orientation (w.r.t. cylinder):	Longitudinal

Final Measurements

Final Width:	3.26	mm
Final Thickness:	8.19	mm
Final Marked Gauge Length:	62.02	mm
Coupon Final Area:	26.7	mm^2

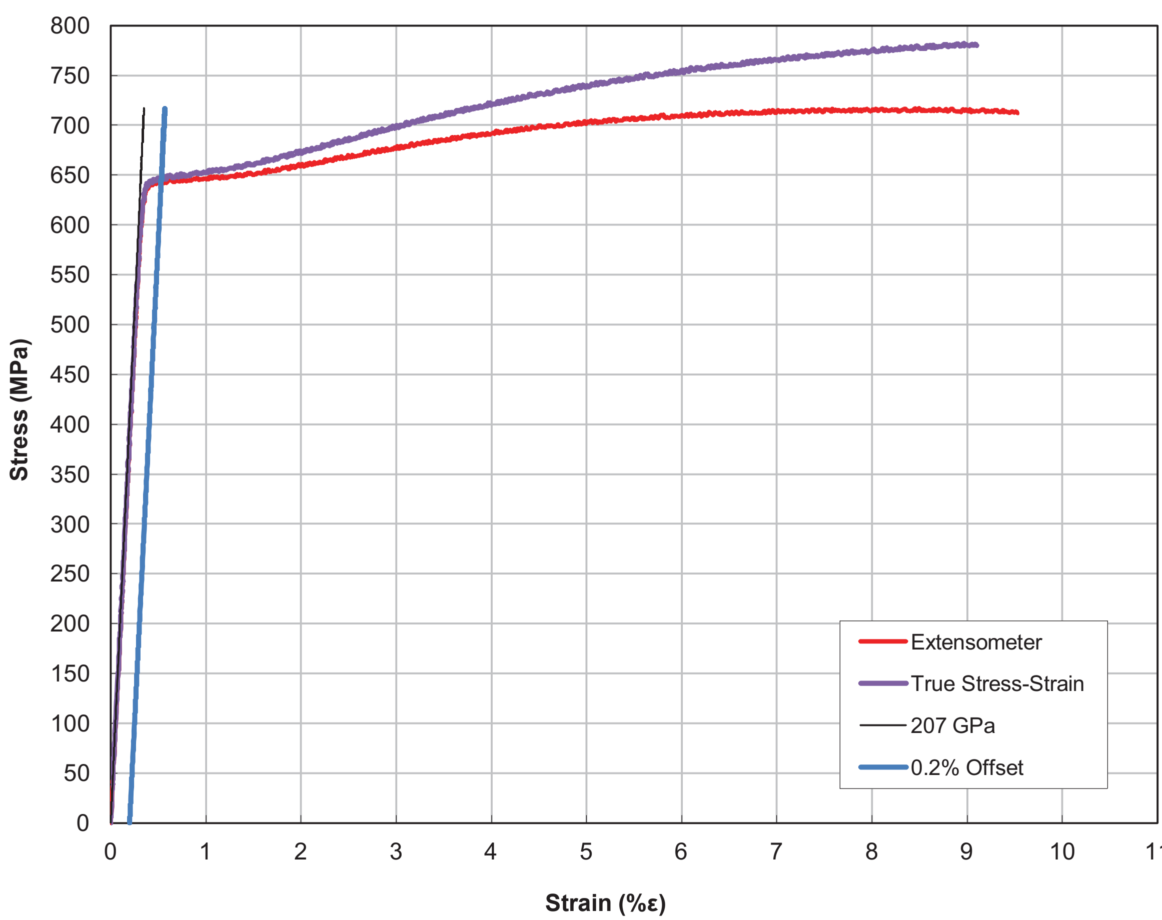
Initial Measurements

Initial Width:	12.83	mm
Initial Thickness:	6.77	mm
Extensometer Gauge Length:	50.8	mm
Initial Marked Gauge Length:	51.02	mm
Coupon initial Area:	86.8	mm^2

Results Summary

Test Date:	25-Mar-07	
Young's Modulus, run #1:	196	GPa
Young's Modulus, run #2:	196	GPa
Young's Modulus, run #3:	193	GPa
Young's Modulus, E, ave.:	195	GPa
Yield Strength (@ 0.2% offset):	644	MPa
Ultimate Strength:	717	MPa
Strain at Ultimate:	8.5	%
Elongation:	21.6	%
Area Reduction:	69	%

Comments:



Coupon Test Report

C-FER Technologies

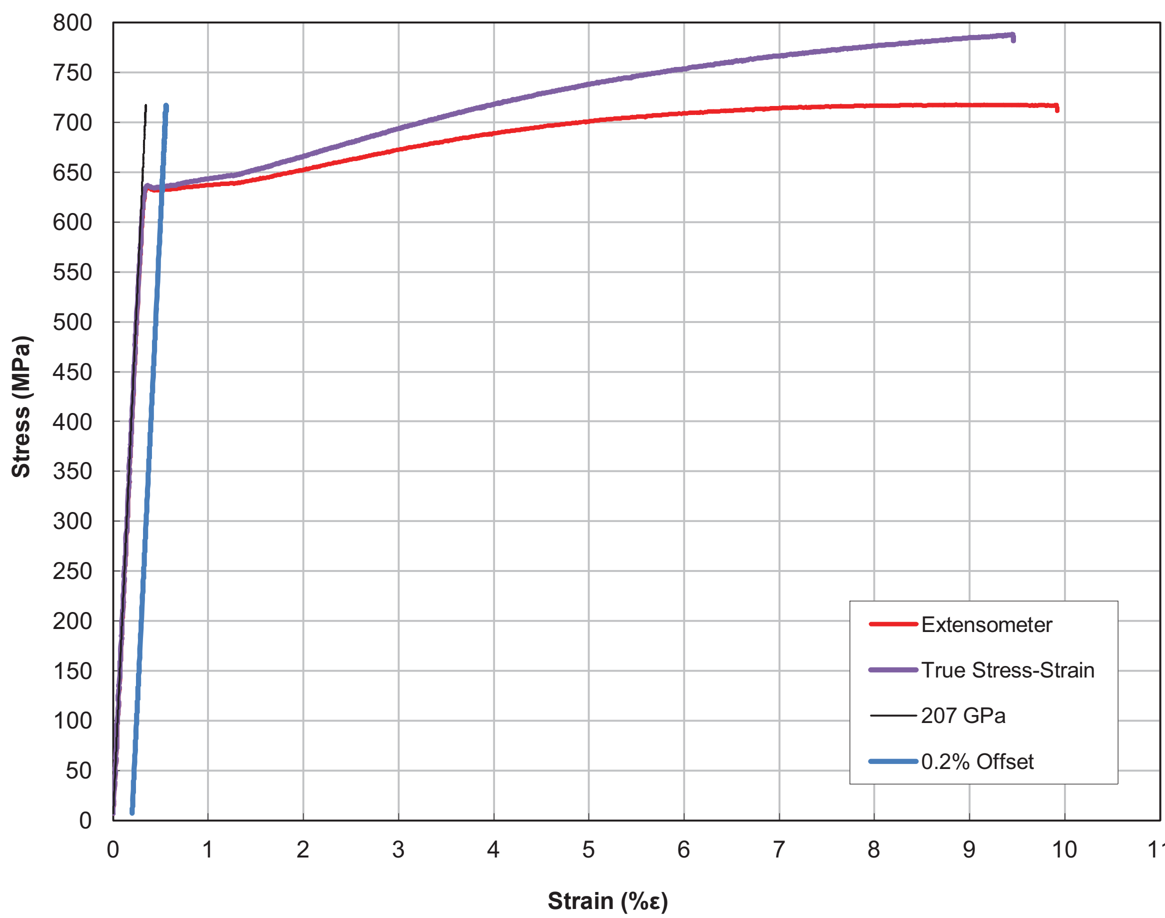
Coupon Identification	
C-FER Project Number:	F034
Coupon Number:	P2C2
Cylinder:	Model B
Coupon Type:	Strip
Test Type:	Tension
Orientation (w.r.t. cylinder):	Hoop

Final Measurements		
Final Width:	3.35	mm
Final Thickness:	8.36	mm
Final Marked Gauge Length:	63.45	mm
Coupon Final Area:	28.0	mm^2

Initial Measurements		
Initial Width:	12.90	mm
Initial Thickness:	6.68	mm
Extensometer Gauge Length:	50.8	mm
Initial Marked Gauge Length:	51.01	mm
Coupon initial Area:	86.1	mm^2

Results Summary		
Test Date:	4-Apr-11	
Young's Modulus, run #1:	201	GPa
Young's Modulus, run #2:	197	GPa
Young's Modulus, run #3:	200	GPa
Young's Modulus, E, ave.:	199	GPa
Yield Strength (@ 0.2% offset):	632	MPa
Ultimate Strength:	717	MPa
Strain at Ultimate:	8.9	%
Elongation:	24.4	%
Area Reduction:	67	%

Comments:



Coupon Test Report

Coupon Identification

C-FER Project Number:	F034
Coupon Number:	P2L1
Cylinder:	Model B
Coupon Type:	Strip
Test Type:	Tension
Orientation (w.r.t. cylinder):	Longitudinal

Final Measurements

Final Width:	3.80	mm
Final Thickness:	8.30	mm
Final Marked Gauge Length:	62.83	mm
Coupon Final Area:	31.5	mm^2

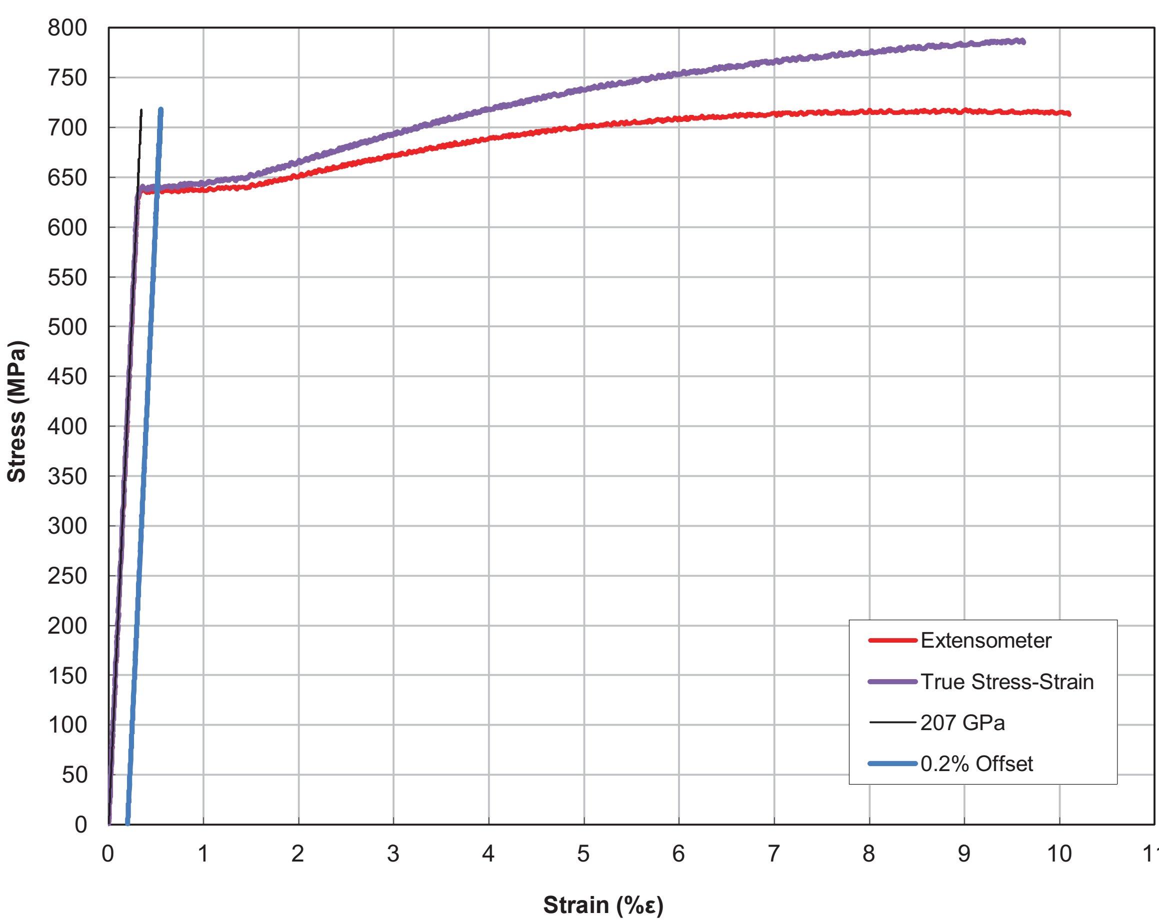
Initial Measurements

Initial Width:	12.89	mm
Initial Thickness:	6.67	mm
Extensometer Gauge Length:	50.8	mm
Initial Marked Gauge Length:	51.34	mm
Coupon initial Area:	85.9	mm^2

Results Summary

Test Date:	26-Mar-11	
Young's Modulus, run #1:	209	GPa
Young's Modulus, run #2:	198	GPa
Young's Modulus, run #3:	206	GPa
Young's Modulus, E, ave.:	204	GPa
Yield Strength (@ 0.2% offset):	638	MPa
Ultimate Strength:	718	MPa
Strain at Ultimate:	9.0	%
Elongation:	22.4	%
Area Reduction:	63	%

Comments:



Coupon Test Report

C-FER Technologies

Coupon Identification

C-FER Project Number:	F034
Coupon Number:	P3C2
Cylinder:	Model C
Coupon Type:	Strip
Test Type:	Tension
Orientation (w.r.t. cylinder):	Hoop

Final Measurements

Final Width:	3.92	mm
Final Thickness:	8.53	mm
Final Marked Gauge Length:	61.94	mm
Coupon Final Area:	33.4	mm^2

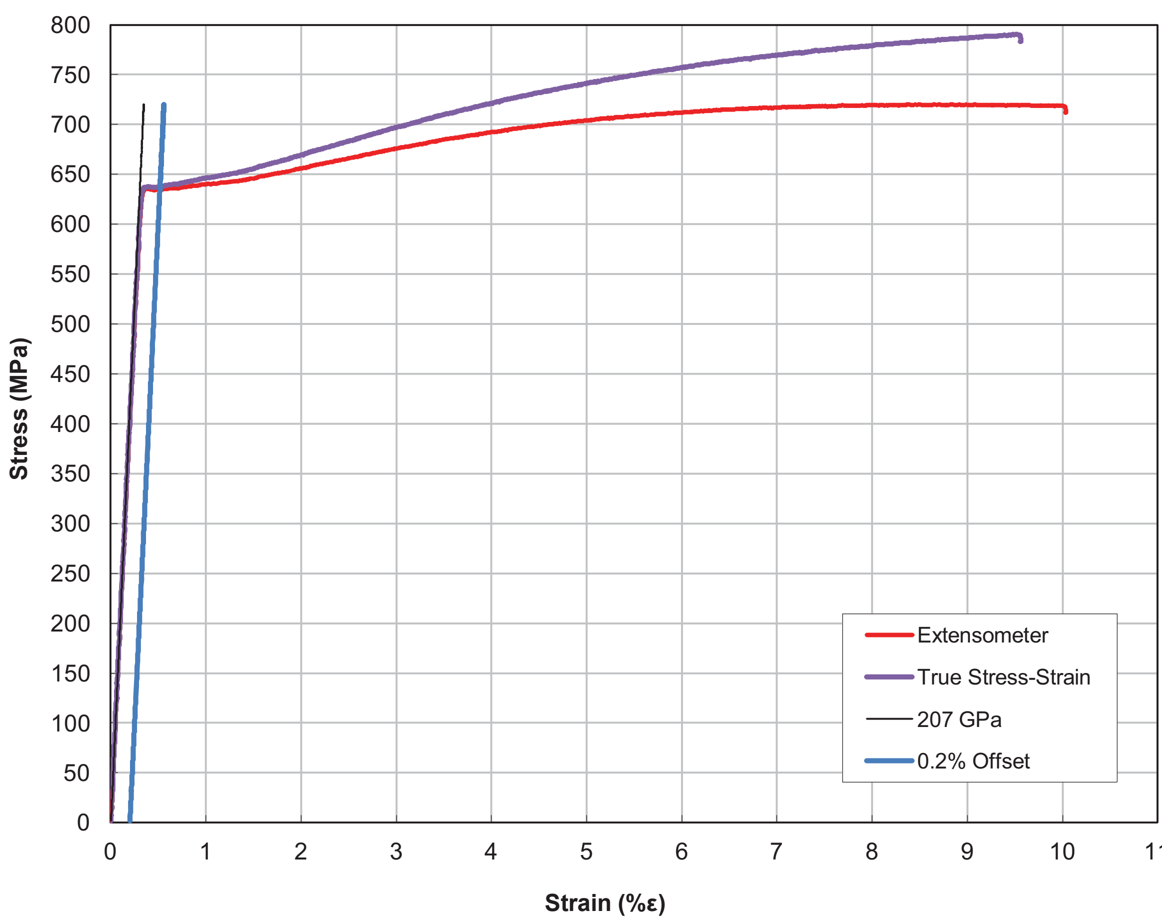
Initial Measurements

Initial Width:	12.89	mm
Initial Thickness:	6.70	mm
Extensometer Gauge Length:	50.8	mm
Initial Marked Gauge Length:	50.94	mm
Coupon initial Area:	86.4	mm^2

Results Summary

Test Date:	29-Mar-11	
Young's Modulus, run #1:	204	GPa
Young's Modulus, run #2:	202	GPa
Young's Modulus, run #3:	204	GPa
Young's Modulus, E, ave.:	203	GPa
Yield Strength (@ 0.2% offset):	634	MPa
Ultimate Strength:	720	MPa
Strain at Ultimate:	8.8	%
Elongation:	21.6	%
Area Reduction:	61	%

Comments:



Coupon Test Report

C-FER Technologies

Coupon Identification

C-FER Project Number:	F034
Coupon Number:	P3L1
Cylinder:	Model C
Coupon Type:	Strip
Test Type:	Tension
Orientation (w.r.t. cylinder):	Longitudinal

Final Measurements

Final Width:	4.18	mm
Final Thickness:	8.13	mm
Final Marked Gauge Length:	63.54	mm
Coupon Final Area:	34.0	mm^2

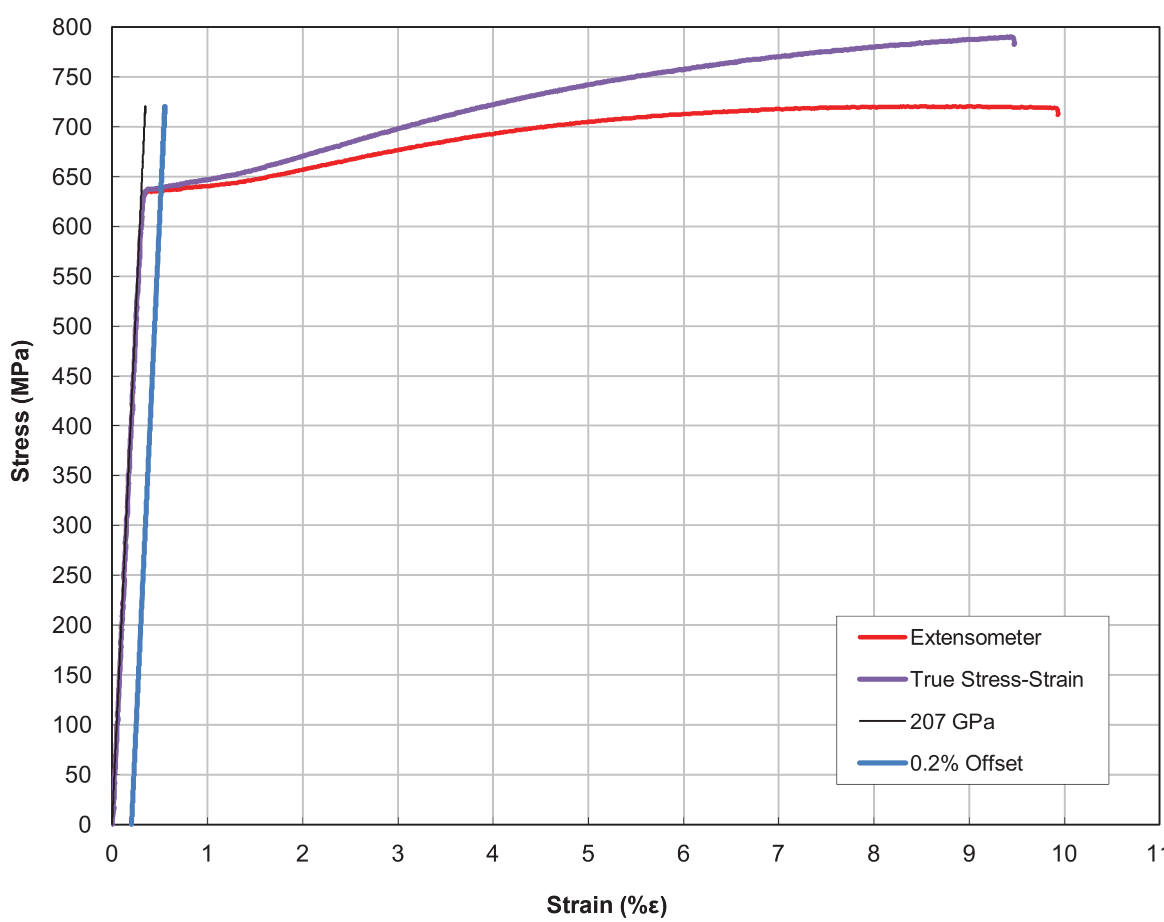
Initial Measurements

Initial Width:	12.89	mm
Initial Thickness:	6.67	mm
Extensometer Gauge Length:	50.8	mm
Initial Marked Gauge Length:	51.69	mm
Coupon initial Area:	86.0	mm^2

Results Summary

Test Date:	29-Mar-11	
Young's Modulus, run #1:	206	GPa
Young's Modulus, run #2:	205	GPa
Young's Modulus, run #3:	202	GPa
Young's Modulus, E, ave.:	205	GPa
Yield Strength (@ 0.2% offset):	635	MPa
Ultimate Strength:	720	MPa
Strain at Ultimate:	8.5	%
Elongation:	22.9	%
Area Reduction:	60	%

Comments:



Annex L Instrumentation Layout

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Cylinder Model A
Corrosion None

Internal Gauges	Uni-axial	22
	Bi-axial	0
External Gauges	Uni-axial	0
	Bi-axial	36

Notes:
Uni-axial gauges are to be oriented in the circumferential direction
Bi-axial gauges are to be aligned with the longitudinal and circumferential axes

Gauges on the Inside of the Cylinder

Angle (degrees)	Axial Location										
	Frame Flange	Frame Flange	Frame Flange	Frame Flange	Frame Flange	Frame Flange	Frame Flange	Frame Flange	Frame Flange	Frame Flange	Frame Flange
	FR 1	FR 2	FR 3	FR 4	FR 5	FR 6	FR 7	FR 8	FR 9	FR 10	FR 11
	120 mm	280 mm	440 mm	600 mm	760 mm	920 mm	1080 mm	1240 mm	1400 mm	1560 mm	1720 mm
0	**Uni-axial**	**Uni-axial**	**Uni-axial**	**Uni-axial**	**Uni-axial**	**Uni-axial**	**Uni-axial**	**Uni-axial**	**Uni-axial**	**Uni-axial**	**Uni-axial**
30	None	None	None	None	None	**Uni-axial**	None	None	None	None	None
60	None	None	None	None	None	**Uni-axial**	None	None	None	None	None
90	None	None	None	None	None	**Uni-axial**	None	None	None	None	None
120	None	None	None	None	None	**Uni-axial**	None	None	None	None	None
150	None	None	None	None	None	**Uni-axial**	None	None	None	None	None
180	None	None	None	None	None	**Uni-axial**	None	None	None	None	None
210	None	None	None	None	None	**Uni-axial**	None	None	None	None	None
240	None	None	None	None	None	**Uni-axial**	None	None	None	None	None
270	None	None	None	None	None	**Uni-axial**	None	None	None	None	None
300	None	None	None	None	None	**Uni-axial**	None	None	None	None	None
330	None	None	None	None	None	**Uni-axial**	None	None	None	None	None

Cylinder **Model A**

Corrosion **None**

Gauges on the Outside of the Cylinder

Angle (degrees)	Axial Location		
	Outside Shell	Outside Shell	Outside Shell
	B/W FRs 1 & 2	B/W FRs 5 & 6	B/W FRs 10 & 11
	FR 1.5	FR 5.5	FR 10.5
	200 mm	840 mm	1640 mm
0	**Bi-axial**	**Bi-axial**	**Bi-axial**
15	None	**Bi-axial**	None
30	None	**Bi-axial**	None
45	None	**Bi-axial**	None
60	**Bi-axial**	**Bi-axial**	**Bi-axial**
75	None	**Bi-axial**	None
90	None	**Bi-axial**	None
105	None	**Bi-axial**	None
120	**Bi-axial**	**Bi-axial**	**Bi-axial**
135	None	**Bi-axial**	None
150	None	**Bi-axial**	None
165	None	**Bi-axial**	None
180	**Bi-axial**	**Bi-axial**	**Bi-axial**
195	None	**Bi-axial**	None
210	None	**Bi-axial**	None
225	None	**Bi-axial**	None
240	**Bi-axial**	**Bi-axial**	**Bi-axial**
255	None	**Bi-axial**	None
270	None	**Bi-axial**	None
285	None	**Bi-axial**	None
300	**Bi-axial**	**Bi-axial**	**Bi-axial**
315	None	**Bi-axial**	None
330	None	**Bi-axial**	None
345	None	**Bi-axial**	None

Cylinder **Model B & Model C**

Corrosion **160x160x1.27mm thinning (clad welded for Model C)**

Internal Gauges	Uni-axial	24
	Bi-axial	2
	Rosette	7
External Gauges	Uni-axial	0
	Bi-axial	15
	Rosette	7

Per Model Totals

Uni-axial	24
Bi-axial	17
Rosette	14

Notes:

Uni-axial gauges are to be oriented in the circumferential direction.

Bi-axial gauges are to be aligned with the longitudinal and circumferential axes.

45° rosettes are to be aligned with two of the gauges in the longitudinal and circumferential directions.

The strain gauge positions are based on a coordinate system with the corrosion patch centred between FRs 5 & 6 at 0°.

Gauges on the Inside of the Cylinder

Angle (degrees)	Axial Location										
	Frame Flange	Frame Flange	Frame Flange	Frame Flange	Frame Flange	Frame Flange	Frame Flange	Frame Flange	Frame Flange	Frame Flange	Frame Flange
	FR 1	FR 2	FR 3	FR 4	FR 5	FR 6	FR 7	FR 8	FR 9	FR 10	FR 11
	120 mm	280 mm	440 mm	600 mm	760 mm	920 mm	1080 mm	1240 mm	1400 mm	1560 mm	1720 mm
0	**Uni-axial**	**Uni-axial**	**Uni-axial**	**Uni-axial**	**Uni-axial**	**Uni-axial**	**Uni-axial**	**Uni-axial**	**Uni-axial**	**Uni-axial**	**Uni-axial**
15	None	None	None	None	None	**Uni-axial**	None	None	None	None	None
30	None	None	None	None	None	**Uni-axial**	None	None	None	None	None
60	None	None	None	None	None	**Uni-axial**	None	None	None	None	None
90	None	None	None	None	None	**Uni-axial**	None	None	None	None	None
120	None	None	None	None	None	**Uni-axial**	None	None	None	None	None
150	None	None	None	None	None	**Uni-axial**	None	None	None	None	None
180	None	None	None	None	None	**Uni-axial**	None	None	None	None	None
210	None	None	None	None	None	**Uni-axial**	None	None	None	None	None
240	None	None	None	None	None	**Uni-axial**	None	None	None	None	None
270	None	None	None	None	None	**Uni-axial**	None	None	None	None	None
300	None	None	None	None	None	**Uni-axial**	None	None	None	None	None
330	None	None	None	None	None	**Uni-axial**	None	None	None	None	None
345	None	None	None	None	None	**Uni-axial**	None	None	None	None	None

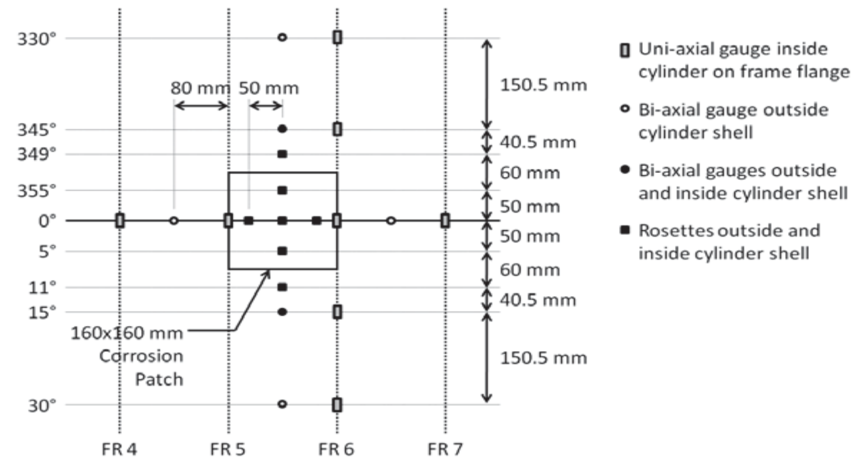
Cylinder Model B & Model C

Corrosion 160x160x1.27mm thinning (clad welded for Model C)

Angle (degrees)	Axial Location				
	Inside Shell	Inside Shell	Inside Shell	Inside Shell	Inside Shell
	B/W FRs 4 & 5	B/W FRs 5 & 6	B/W FRs 5 & 6	B/W FRs 5 & 6	B/W FRs 6 & 7
	FR 4.5	FR 5.1875	FR 5.5	FR 5.8125	FR 6.5
	680 mm	790 mm	840 mm	890 mm	1000 mm
0	None	**Rosette**	**Rosette**	**Rosette**	None
5	None	None	**Rosette**	None	None
11	None	None	**Rosette**	None	None
15	None	None	**Bi-axial**	None	None
30	None	None	None	None	None
60	None	None	None	None	None
90	None	None	None	None	None
120	None	None	None	None	None
150	None	None	None	None	None
180	None	None	None	None	None
210	None	None	None	None	None
240	None	None	None	None	None
270	None	None	None	None	None
300	None	None	None	None	None
330	None	None	None	None	None
345	None	None	**Bi-axial**	None	None
349	None	None	**Rosette**	None	None
355	None	None	**Rosette**	None	None

Gauges on the Outside of the Cylinder

Angle (degrees)	Axial Location				
	Outside Shell	Outside Shell	Outside Shell	Outside Shell	Outside Shell
	B/W FRs 4 & 5	B/W FRs 5 & 6	B/W FRs 5 & 6	B/W FRs 5 & 6	B/W FRs 6 & 7
	FR 4.5	FR 5.1875	FR 5.5	FR 5.8125	FR 6.5
	680 mm	790 mm	840 mm	890 mm	1000 mm
0	**Bi-axial**	**Rosette**	**Rosette**	**Rosette**	**Bi-axial**
5	None	None	**Rosette**	None	None
11	None	None	**Rosette**	None	None
15	None	None	**Bi-axial**	None	None
30	None	None	**Bi-axial**	None	None
60	None	None	**Bi-axial**	None	None
90	None	None	**Bi-axial**	None	None
120	None	None	**Bi-axial**	None	None
150	None	None	**Bi-axial**	None	None
180	None	None	**Bi-axial**	None	None
210	None	None	**Bi-axial**	None	None
240	None	None	**Bi-axial**	None	None
270	None	None	**Bi-axial**	None	None
300	None	None	**Bi-axial**	None	None
330	None	None	**Bi-axial**	None	None
345	None	None	**Bi-axial**	None	None
349	None	None	**Rosette**	None	None
355	None	None	**Rosette**	None	None



Model A

Internal Gauges		
T-Frame No.	External Specimen Reference	Gauge
1	180	iFR1 0
2	180	iFR2 0
3	180	iFR3 0
4	180	iFR4 0
5	180	iFR5 0
6	180	iFR6 0
6	210	iFR6 30
6	240	iFR6 60
6	270	iFR6 90
6	300	iFR6 120
6	330	iFR6 150
6	360	iFR6 180
6	30	iFR6 210
6	60	iFR6 240
6	90	iFR6 270
6	120	iFR6 300
6	150	iFR6 330
7	180	iFR7 0
8	180	iFR8 0
9	180	iFR9 0
10	180	iFR10 0
11	180	iFR11 0

Model A

External Gauges		
T-Frame No.	External Specimen Reference	Gauge
1.5	180	FR 1.5 0 X
1.5	180	FR 1.5 0 y
1.5	240	FR 1.5 60 X
1.5	240	FR 1.5 60 Y
1.5	300	FR 1.5 120 X
1.5	300	FR 1.5 120 Y
1.5	0	FR 1.5 180 X
1.5	0	FR 1.5 180 Y
1.5	60	FR 1.5 240 X
1.5	60	FR 1.5 240 Y
1.5	120	FR 1.5 300 X
1.5	120	FR 1.5 300 Y
5.5	180	FR 5.5 0 X
5.5	180	FR 5.5 0 Y
5.5	195	FR 5.5 15 X
5.5	195	FR 5.5 15 Y
5.5	210	FR 5.5 30 X
5.5	210	FR 5.5 30 Y
5.5	225	FR 5.5 45 X
5.5	225	FR 5.5 45 Y
5.5	240	FR 5.5 60 X
5.5	240	FR 5.5 60 Y
5.5	255	FR 5.5 75 X
5.5	255	FR 5.5 75 Y
5.5	270	FR 5.5 90 X
5.5	270	FR 5.5 90 Y
5.5	285	FR 5.5 105 X
5.5	285	FR 5.5 105 Y
5.5	300	FR 5.5 120 X
5.5	300	FR 5.5 120 Y
5.5	315	FR 5.5 135 X
5.5	315	FR 5.5 135 Y
5.5	330	FR 5.5 150 X
5.5	330	FR 5.5 150 Y
5.5	345	FR 5.5 165 X
5.5	345	FR 5.5 165 Y
5.5	0	FR 5.5 180 X
5.5	0	FR 5.5 180 Y
5.5	15	FR 5.5 195 X
5.5	15	FR 5.5 195 Y
5.5	30	FR 5.5 210 X
5.5	30	FR 5.5 210 Y
5.5	45	FR 5.5 225 X
5.5	45	FR 5.5 225 Y
5.5	60	FR 5.5 240 X
5.5	60	FR 5.5 240 Y
5.5	75	FR 5.5 255 X
5.5	75	FR 5.5 255 Y
5.5	90	FR 5.5 270 X
5.5	90	FR 5.5 270 Y
5.5	105	FR 5.5 285 X
5.5	105	FR 5.5 285 Y
5.5	120	FR 5.5 300 X

Model A

External Gauges		
T-Frame No.	External Specimen Reference	Gauge
5.5	120	FR 5.5 300 Y
5.5	135	FR 5.5 315 X
5.5	135	FR 5.5 315 Y
5.5	150	FR 5.5 330 X
5.5	150	FR 5.5 330 Y
5.5	165	FR 5.5 345 X
5.5	165	FR 5.5 345 Y
10.5	180	FR 10.5 0 X
10.5	180	FR 10.5 0 Y
10.5	240	FR 10.5 60 X
10.5	240	FR 10.5 60 Y
10.5	300	FR 10.5 120 X
10.5	300	FR 10.5 120 Y
10.5	0	FR 10.5 180 X
10.5	0	FR 10.5 180 Y
10.5	60	FR 10.5 240 X
10.5	60	FR 10.5 240 Y
10.5	120	FR 10.5 300 X
10.5	120	FR 10.5 300 Y

Decimals in T-frame No. represents the fraction of total mid-bay length the gauge extends toward the next T-frame

Model B & C

Internal Gauges		
T-Frame No.	External Specimen Reference	Gauge
1	180	iFR1 0 y
2	180	iFR2 0 y
3	180	iFR3 0 y
4	180	iFR4 0 y
5	180	iFR5 0 y
5-1875	180	iFR 5-1875 0 x
5-1875	180	iFR 5-1875 0 xy
5-1875	180	iFR 5-1875 0 y
5.5	180	iFR 5-5 0 x
5.5	180	iFR 5-5 0 xy
5.5	180	iFR 5-5 0 y
5.5	175	iFR 5-5 5 x
5.5	175	iFR 5-5 5 xy
5.5	175	iFR 5-5 5 y
5.5	169	iFR 5-5 11 x
5.5	169	iFR 5-5 11 xy
5.5	169	iFR 5-5 11 y
5.5	165	iFR 5-5 15 x
5.5	165	iFR 5-5 15 y
5.5	345	iFR 5-5 165 x
5.5	345	iFR 5-5 165 y
5.5	349	iFR 5-5 169 x
5.5	349	iFR 5-5 169 xy
5.5	349	iFR 5-5 169 y
5.5	355	iFR 5-5 175 x
5.5	355	iFR 5-5 175 xy
5.5	355	iFR 5-5 175 y
5.8125	180	iFR 5-8125 0 x
5.8125	180	iFR 5-8125 0 xy
5.8125	180	iFR 5-8125 0 y
6	180	iFR6 0 y
6	165	iFR6 15 y
6	150	iFR6 30 y
6	120	iFR6 60 y
6	90	iFR6 90 y
6	60	iFR6 120 y
6	30	iFR6 150 y
6	360	iFR6 180 y
6	330	iFR6 210 y
6	300	iFR6 240 y
6	270	iFR6 270 y
6	240	iFR6 300 y
6	210	iFR6 330 y
6	225	iFR6 345 y
7	180	iFR7 0 y
8	180	iFR8 0 y
9	180	iFR9 0 y
10	180	iFR10 0 y
11	180	iFR11 0 y

Decimals in T-frame No. represents the fraction of total mid-bay length the gauge extends toward the next T-frame

Model B & C

External Gauges		
T-Frame No.	External Specimen Reference	Gauge
4.5	180	FR 4-5 0 X
4.5	180	FR 4-5 0 Y
5.1875	180	FR 5-1875 0 X
5.1875	180	FR 5-1875 0 XY
5.1875	180	FR 5-1875 0 Y
5.5	180	FR 5-5 0 X
5.5	180	FR 5-5 0 XY
5.5	180	FR 5-5 0 Y
5.5	185	FR 5-5 5 X
5.5	185	FR 5-5 5 XY
5.5	185	FR 5-5 5 Y
5.5	191	FR 5-5 11 X
5.5	191	FR 5-5 11 XY
5.5	191	FR 5-5 11 Y
5.5	195	FR 5-5 15 X
5.5	195	FR 5-5 15 Y
5.5	210	FR 5-5 30 X
5.5	210	FR 5-5 30 Y
5.5	240	FR 5-5 60 X
5.5	240	FR 5-5 60 Y
5.5	270	FR 5-5 90 X
5.5	270	FR 5-5 90 Y
5.5	300	FR 5-5 120 X
5.5	300	FR 5-5 120 Y
5.5	330	FR 5-5 150 X
5.5	330	FR 5-5 150 Y
5.5	0	FR 5-5 180 X
5.5	0	FR 5-5 180 Y
5.5	30	FR 5-5 210 X
5.5	30	FR 5-5 210 Y
5.5	60	FR 5-5 240 X
5.5	60	FR 5-5 240 Y
5.5	90	FR 5-5 270 X
5.5	90	FR 5-5 270 Y
5.5	120	FR 5-5 300 X
5.5	120	FR 5-5 300 Y
5.5	150	FR 5-5 330 X
5.5	150	FR 5-5 330 Y
5.5	165	FR 5-5 345 X
5.5	165	FR 5-5 345 Y
5.5	169	FR 5-5 349 X
5.5	169	FR 5-5 349 XY
5.5	169	FR 5-5 349 Y
5.5	175	FR 5-5 355 X
5.5	175	FR 5-5 355 XY
5.5	175	FR 5-5 355 Y
5.8125	180	FR 5-8125 0 X
5.8125	180	FR 5-8125 0 XY
5.8125	180	FR 5-8125 0 Y
6.5	180	FR 6-5 0 X
6.5	180	FR 6-5 0 Y

Decimals in T-frame No. represents the fraction of total mid-bay length the gauge extends toward the next T-frame

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Annex M Collapse Test Procedure

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DRDC-ATLANTIC COLLAPSE TEST PROGRAM

Procedure for Collapse Tests

1. Test Description

The project involves the design and collapse testing of three large-scale ring-stiffened cylinders. The intent is for one "baseline" cylinder to be tested, followed by one with simulated corrosion damage and then one with similar damage that has been repaired by weld buttering. Collapse testing involves subjecting each specimen to a progressively increasing external pressure until a sudden reduction in external pressure is noticed, signifying collapse.

2. Instrumentation and Data Acquisition

2.1. Instrumentation will consist of two (2) calibrated pressure transducers (DEC and specimen interior pressure), two (2) water volume meters and the following number and type of strain gauges:

2.1.1. Model A

- Exterior: 36 biaxial strain gauges
- Interior: 22 uniaxial strain gauges

2.1.2. Models B & C:

- Exterior: 24 uniaxial, 2 biaxial and 7 rosette strain gauges
- Interior: 15 biaxial and 7 rosette strain gauges

2.2. All data shall be acquired via C-FER's computer-controlled software and signal conditioning system.

3. Installation, Test Preparations

3.1. All specimens are to be tested in C-FER's 8,500-psi Deepwater Experimental Chamber (DEC).

3.2. Prior to specimen installation, test engineer is to confirm completion of all pretest geometric measurements.

3.3. Photographs are to be taken of pertinent operations (specimen setup, transport, installation, removal).

3.4. Apply internal strain gauges and confirm that they pass waterproofing verification.

3.5. Weld caps on to specimen.

3.6. Apply external strain gauges and confirm that they all pass waterproofing verification.

3.7. Install assembly in DEC, ensuring that no strain gauges or strain gauges wires are damaged in the process.

3.8. Hook up high pressure fill and vent lines to end cap fittings.

3.9. Close DEC doors, and fill the DEC and specimen with water.

3.10. Set-up instrumentation to record interior DEC pressure, interior specimen pressure and water volume.

3.11. Balance and zero instrumentation prior to proceeding with testing.

3.12. Set automatic read capability of data acquisition system to record pressure and strain at rate of 100 Hz, and every five (5) seconds.

4. Test Procedure

4.1. Confirm that the specimen vent line valve is closed.

4.2. Simultaneously pressurize both DEC and specimen at a rate not exceeding 300 psi/minute and ensure that the net pressure (DEC pressure minus specimen pressure) does not exceed 100-psi.

4.3. Stop pumping once the DEC pressure reaches 1,000-psi. Visually inspect the DEC for any possible leaks and ensure that the DEC and specimen pressures are maintained during the inspection.

4.4. After the inspection, continue to pressurize the DEC and specimen until they reach a pressure greater than the predicted collapse pressure but no greater than 2,000-psi (max. pressure rating of pressure transducers).

4.5. Stop pumping and isolate the DEC and specimen.

4.6. Slowly open the needle valve that restricts the specimen vent and allow water to bleed out.

4.7. Continue to bleed water out of the specimen until collapse occurs.

4.8. During intervals where the inlet water tank to the DEC requires refilling or the specimen vent tank requires emptying, the specimen and DEC shall be isolated to ensure that no water can exit either the specimen or the DEC.

4.9. Upon completion of testing, drain specimen and DEC, open DEC doors, and remove specimen from DEC.

4.10. Check and backup computer file containing test results.

4.11. Take photographs.

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C-FER Technologies (1999) Inc. ("C-FER") was awarded Contract Number W7707-098210/001/HAL with Public Works and Government Services Canada ("PWGSC") to design, fabricate and test large scale ring stiffened cylinders. The objective of this project was to assess the impact on the collapse pressure of submarine pressure hulls of metal loss due to corrosion, with and without subsequent weld buttering repair. C-FER and Martec Limited ("Martec") contributed to the preparation of this report and the work. Martec was responsible for the final cylinder design and finite element (FE) analysis, while C-FER was responsible for providing technical support on the end cap design, collapse testing facilities, testing expertise and overall project coordination. The three specimens, designated as Specimen A – Baseline, Specimen B – Damaged and Specimen C – Repaired, were fabricated and tested, and the resulting collapse pressures were 7.75, 7.31 and 7.66 MPa, respectively. The simulated corrosion damage (i.e. metal loss) reduced the collapse capacity by 5.9%, whereas repair of simulated corrosion damage by metal replacement through weld buttering recovered 4.8% of that capacity. The findings indicate that weld buttering can be an effective corrosion repair technique.

C-FER Technologies (1999) Inc. s'est vue attribuer le contrat W7707-098210/001/HAL par Travaux publics et Services gouvernementaux Canada (TPSGC) pour la conception, la fabrication et l'essai de cylindres à grande échelle renforcés à l'aide d'anneaux. L'objectif de ce projet était d'évaluer l'impact, sur la pression d'effondrement de coques épaisses de sous-marins, de la perte de métal par corrosion, avec et sans beurrage subséquent. C-FER et Martec Limited ont contribué à la préparation du présent rapport et aux travaux. Martec était responsable de la conception finale des cylindres et de l'analyse par éléments finis, alors que C-FER était chargée de fournir du soutien technique portant sur la conception du bouchon d'extrémité, ainsi que les installations d'essai d'effondrement, l'expertise d'essai, et de faire la coordination du projet. Les trois spécimens, désignés de la façon suivante : spécimen A – point de comparaison, spécimen B – endommagé, et spécimen C – réparé, ont été fabriqués et testés, et les pressions d'effondrement résultantes étaient de 7,75, 7,31 et 7,66 MPa respectivement. Les dommages par corrosion simulés (c.-à-d. les pertes de métal) ont réduit la capacité d'effondrement de 5,9 %, alors que la réparation des dommages par corrosion simulés par remplacement de métal par beurrage a permis de récupérer 4,8 % de cette capacité. Les conclusions indiquent que le beurrage peut être une technique de réparation de la corrosion efficace.

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submarine pressure hull; corrosion damage; hull thinning; weld repair; buttering; collapse pressure; experimental mechanics

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